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DEPARTMENT OF NATURAL RESOURCES

MINERAL COMMODITIES OF CALIFORNIA

Bulletin 156
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DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO

STATE OF CALIFORNIA
EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
WARREN T. HANNUM, Director

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO 11
OLAF P. JENKINS, Chief

SAN FRANCISCO BULLETIN 156 AUGUST 1950

MINERAL COMMODITIES OF CALIFORNIA

GEOLOGIC OCCURRENCE, ECONOMIC DEVELOPMENT, AND UTILIZATION OF THE STATE'S MINERAL RESOURCES

Prepared by the Staff of the
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Under the Direction of
OLAF P. JENKINS

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UNITED STATES DEPARTMENT OF THE INTERIOR, BUREAU OF MINES

LETTER OF TRANSMITTAL

To His Excellency, The Honorable Earl Warren
Governor of the State of California

Dear Sir: I have the honor to transmit herewith Bulletin 156, *Mineral Commodities of California*, prepared by the staff of the Division of Mines under the direction of its Chief, Olaf P. Jenkins.

The subtitle of the book, *Geologic occurence, economic development, and utilization of the State's mineral resources,* indicates its broad scope and practical nature. Its appearance is particularly timely since this is a period of industrial expansion of the State. The volume reviews by means of separate technical papers the entire mineral industry of California; over 80 different kinds of raw mineral materials are discussed, nearly all of which, during times of favorable economic conditions, are capable of some profitable development and use in some industry of the state.

California's productive mineral wealth during 1948 finally exceeded one billion dollars, which is three times the dollar value recorded a decade ago. During 1948 over 60 different kinds of minerals were produced commercially, each of the 58 counties contributing to the production. Only a few of the basic minerals needed by industries in this state have yet to be found in sufficient quantities within its borders to be profitably mined. California is, therefore, endowed with deposits of nearly every known mineral, making it capable of being nearly self-sustaining in providing its various industries with the raw mineral materials they need.

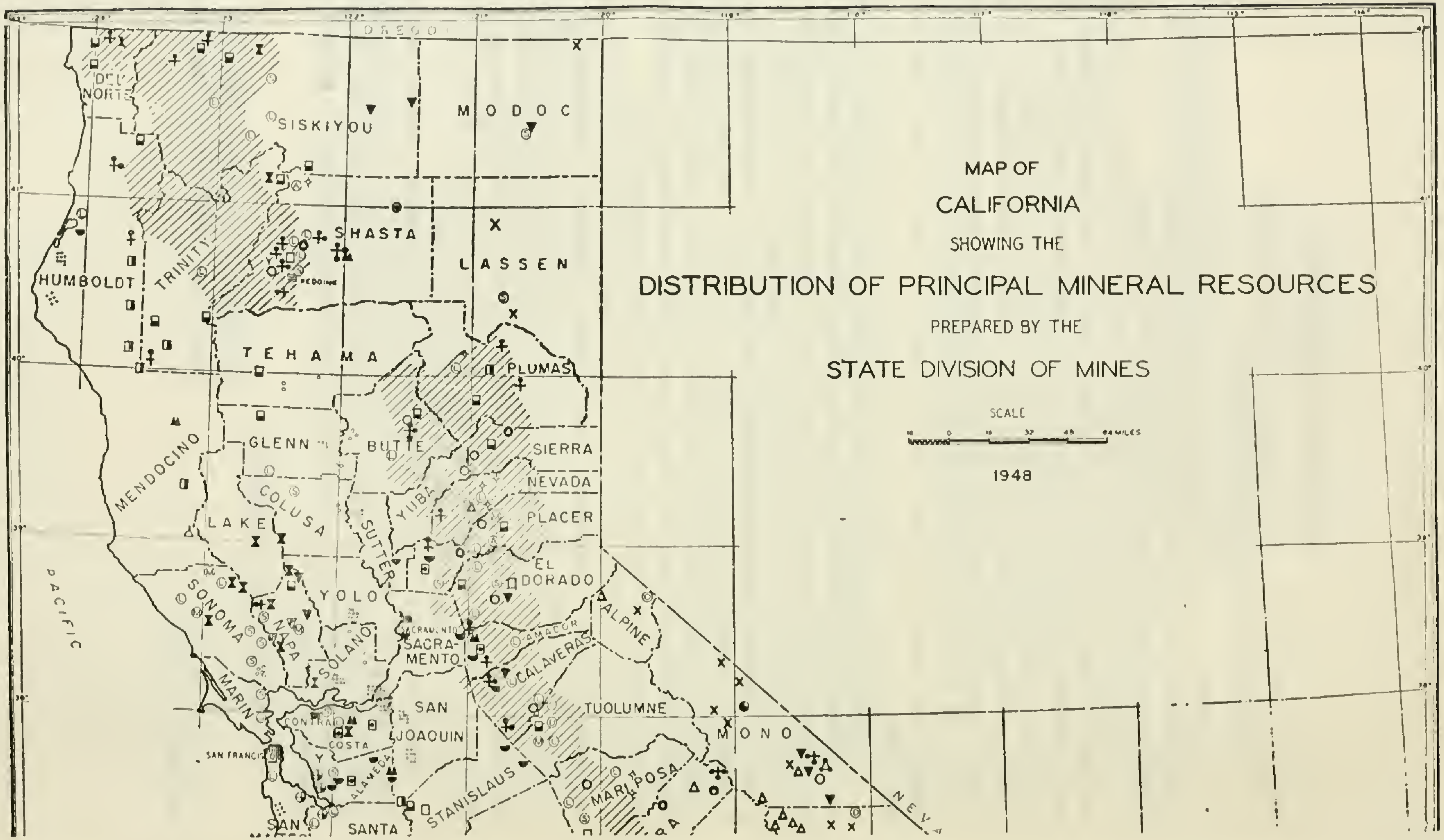
The entire technical staff of the Division of Mines has been engaged in the enterprise of preparing this volume. Eighteen of its members represent actual authors, and one member in particular, Lauren A. Wright, served as the principal technical editor. The latest statistical data were supplied, through cooperative agreement, by the federal Bureau of Mines, while the earlier production figures were drawn largely from the Division's own records and recast in the form of graphs.

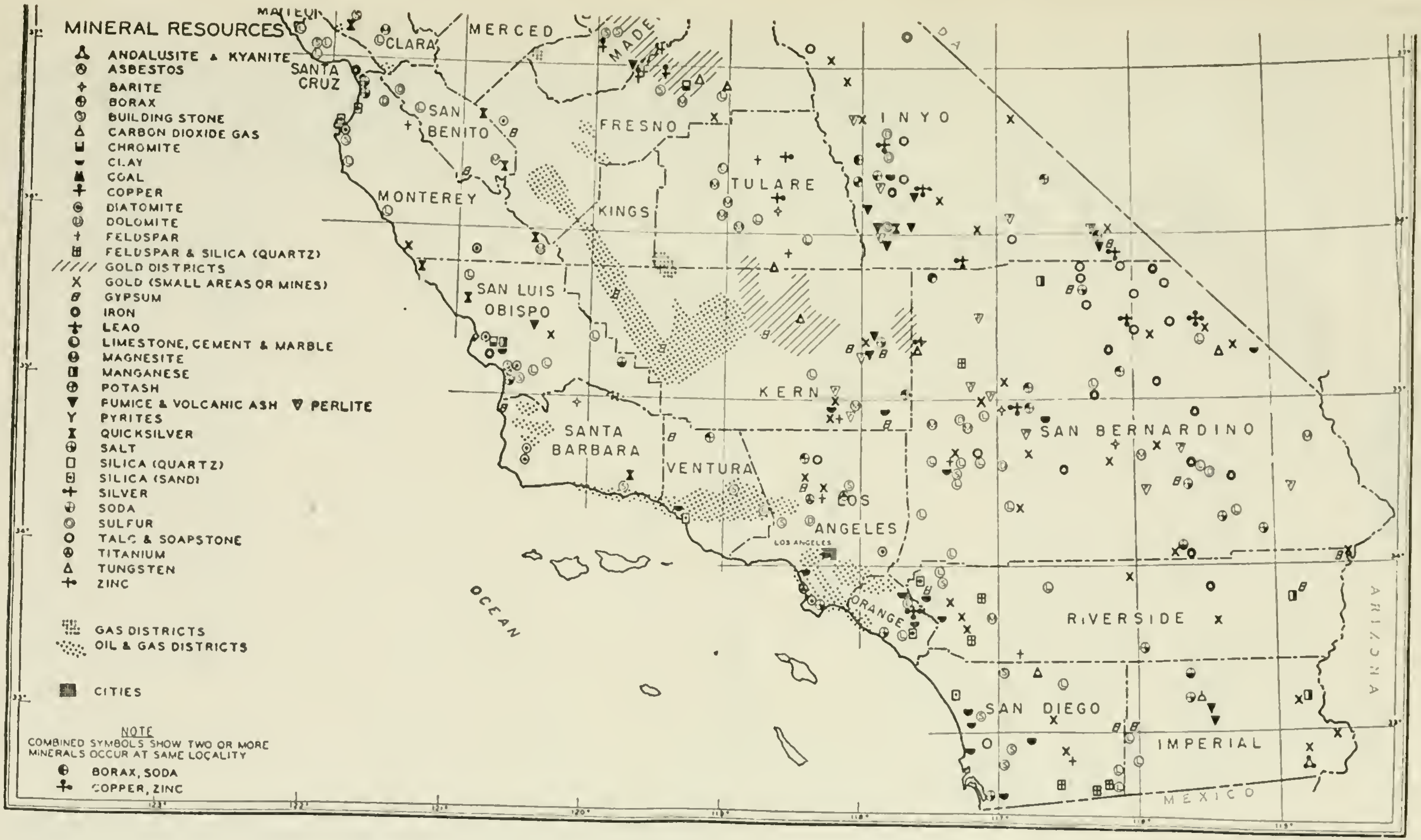
As a handbook of useful knowledge concerning the mineral resources and industry of California, Bulletin 156 should serve a very broad field of interest. Explorer, producer, and user of mineral materials, together with the general public seeking authoritative information, should welcome this volume.

Respectfully submitted,

Warren T. Hannum, Director
Department of Natural Resources

February 1, 1950


MAP OF
CALIFORNIA
SHOWING THE
DISTRIBUTION OF PRINCIPAL MINERAL RESOURCES
PREPARED BY THE
STATE DIVISION OF MINES
SCALE
1948
OREGON
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
MENDOCINO
GLENN
BUTTE
SIERRA
NEVADA
PLACER
COLUSA
SUTTER
YUBA
LAKE
EL DORADO
YOLO
SONOMA
NAPA
SOLANO
SACRAMENTO
AMADOR
ALPINE
CALAVERAS
MARIN
SAN FRANCISCO
CONTRA COSTA
SAN JOAQUIN
TUOLUMNE
MONO
ALAMEDA
STANISLAUS
MARIPOSA
SAN MATEO
SANTA
NEVADA
PACIFIC


MINERAL RESOURCES
ANDALUSITE & KYANITE
ASBESTOS
BARITE
BORAX
BUILDING STONE
CARBON DIOXIDE GAS
CHROMITE
CLAY
COAL
COPPER
DIATOMITE
DOLOMITE
FELDSPAR
FELDSPAR & SILICA (QUARTZ)
GOLD DISTRICTS
GOLD (SMALL AREAS OR MINES)
GYPSUM
IRON
LEAD
LIMESTONE, CEMENT & MARBLE
MAGNESITE
MANGANESE
POTASH
PUMICE & VOLCANIC ASH
PERLITE
PYRITES
QUICKSILVER
SALT
SILICA (QUARTZ)
SILICA (SAND)
SILVER
SODA
SULFUR
TALC & SOAPSTONE
TITANIUM
TUNGSTEN
ZINC
GAS DISTRICTS
OIL & GAS DISTRICTS
CITIES
NOTE
COMBINED SYMBOLS SHOW TWO OR MORE MINERALS OCCUR AT SAME LOCALITY
BORAX, SODA
COPPER, ZINC
MATEO
CLARA
SANTA CRUZ
SAN BENITO
MONTEREY
MERCED
MADERA
FRESNO
KINGS
INYO
TULARE
SAN LUIS OBISPO
KERN
SANTA BARBARA
VENTURA
LOS ANGELES
LOS ANGELES
SAN BERNARDINO
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
ARIZONA
MEXICO
OCEAN

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PREFACE

In assembling the material prepared for this bulletin, a five-fold division has been made as follows:

Part 1, Summary of mineral wealth of California for 1948
Part 2, Mineral fuels
Part 3, Industrial minerals
Part 4, Metals
Part 5, Directory of mineral producers, dealers, and commercial laboratories

Part 1 summarizes the mineral statistics for California by mineral substance and by counties for the years 1948 and 1947. The data represent the results of work by the United States Bureau of Mines in cooperation with the State Division of Mines, accompanied by a text prepared by staff members of the Division of Mines.

Parts 2, 3, and 4 consist of individual commodity reports compiled by staff members, and make up the principal text of this bulletin.

Part 5 consists of tables and lists of dealers, laboratories, and mineral producers in the state.

Parts 1 and 5 contain information that customarily is used in the annual statistical bulletin of the Division of Mines, while Parts 2, 3, and 4 represent an entirely new contribution.

To bring under one cover a resumé of each mineral commodity of California, its geologic occurrence, mineralogy, distribution, utilization, economics, mining, and production, is the principal aim of this bulletin. Further details of the subject may be found in various records of more extensive investigations, references to which are given. Although most of the previous reports available to our authors have already been published, others are still in preparation. Unfortunately, however, on some of the commodities very little detailed work has yet been started and in these cases our bulletin falls short of being adequate.

To comprehend the intention and scope of this bulletin, let us glance around at the many material things we use today and trace them to their original source. Let us consider how many of these useful materials represent products manufactured from the constituents of the earth itself, namely, minerals and rocks. These may include the plaster of the walls, pigments in the paint, bricks of the fireplace, glass in the windows, filaments of the lights, china in the cupboard, metals of the kitchen utensils and of our automobiles, fuels we use, coins in our pockets, and the very soils of the earth which help to grow our food, and provide raw products that, combined with minerals, are employed to manufacture every material thing we use today.

The mineral commodities of California may, therefore, be defined as the useful constituents of the earth as found in the state's area of over 158,000 square miles. As the population has grown in this state from six million to eleven million during the last few years, many new industries have been developed on the West Coast to take care of the demands of the increased number of persons living in this region. Each industry represents a market for mineral materials obtained locally or imported.

As the needs of industry are made known, available sources of suitable minerals will be provided, local or out-of-state. During this time of new industrial development, however, the local producer is not well informed of the needs of industry, nor is industry always aware of the vast local resources of minerals available. It is the intention of this bulletin, therefore, to provide information summarizing the salient features of each mineral commodity which has been developed in California.

The data for this volume have been secured principally from available published sources, some of which are quite recent, or still in preparation as, for example, the federal reports on strategic minerals. There has also been included much new material which has never before been published, but has only recently been secured during current studies by staff members of the Division of Mines and by cooperating agencies. Among the materials now being studied are talc, pumice and perlite, gypsum, limestone and dolomite, clays, salines, and kyanite. Since the planned program of the Division of Mines calls for continued investigations of the state's mineral commodities, there will be need, from time to time, of considerable revision of the material assembled in this bulletin.

That the State of California has entered into a new era of mineral expansion is now well recognized and clearly indicated by the recent records of mineral production. Even though the mining of metalliferous minerals has shown a serious decline, the production of nonmetals, or the so-called industrial minerals, has made amazing advancements. Minerals of this class often represent resources which must be developed and treated on a very large scale in close proximity to market areas. Where metals require comparatively little attention to the problems of marketing and transportation, industrial minerals are principally controlled in their development by these economic factors and the ability of the producer to sell his product, which in turn is governed by the general growth of population and its demands. Compare the difference in economic problems between the gold miner and the clay producer. Labor in the gold mines is paid on the basis of the prevailing wage, but the product is sold to the United States Mint at a fixed price. The clay producer, on the other hand, provides materials which must be processed to make ceramic ware, and this ware must be marketed profitably in the face of competition.

The entire picture for the mineral industry is thus changing rapidly in California as general economic conditions change with the advance of the state's civilization. It is fortunate for California that its mineral resources are plentiful and diversified. Nearly any changing situation can be met in this state when the basic economic facts are understood. Exploration and development of minerals for industries must be preceded by a knowledge of the needs of the industries and an understanding of the complex economic problems involved.

The task of preparing the material for this bulletin has been distributed among seventeen members of the technical staff, each of whom has been required to make a careful study of several different commodities and prepare a special report on each one. Each report has been technically edited by one of the principal authors, namely, Lauren A. Wright, in order to effect continuity. The latest statistical data were then added, and graphs showing past production and other economic factors were included. Subject matter for each commodity report has been, in general, arranged as follows:

Significance of the commodity
Geologic occurrence
Mineralogy
Distribution
Utilization
Markets
Mining methods and treatment
History of production

It is the intention of Bulletin 156 to cover the whole field of mineral resources and mineral industry. If earlier statistical figures are desired, Bulletins 130 and 139 of the Division are recommended. If a resumé of mineral resources of each county is wanted, the reader is referred to Bulletin 142. It is hoped that the present volume will fill a long-felt need of a summary of the whole field of mineral commodities in California.

OLAF P. JENKINS
Chief, Division of Mines

San Francisco
February 1, 1950

NATURAL ENVIRONMENT OF MINERAL RESOURCES OF CALIFORNIA

By Olaf P. Jenkins

Introduction. A study of the map of California showing the distribution of its developed mineral deposits suggests a pattern which is not haphazard, but is controlled by certain basic features. Both natural and cultural features affect the controls. Where the deposits are of commodities limited in extent and of high unit value, as are metals and fuels, their distribution is entirely controlled by natural environment. On the other hand, where the deposits represent commodities which are practically unlimited in extent, as are sand and gravel, the distribution is controlled not only by natural environment but by proximity to markets. More exacting demands in industry, however, may require improvement of grade, which is accomplished either by finding more suitable deposits at distant localities, or by processing the minerals near at hand. In general, however, the nonmetallic mineral commodities represent the more abundant resources, and a map of their distribution indicates that they cluster about the great centers of population, while the minerals of greater unit value are located only in the natural provinces suited to their environment. In consideration of the natural environment of mineral deposits, the following discussion may help to explain some of the various geologic factors involved in the commodity studies of this volume.

Classification of Rocks. Rock formations, in contrast to mineral deposits, are the larger geologic bodies which make up the earth's crust. A rock may be made up principally of a single kind of mineral, as, for example, dolomite, but generally it is composed of an aggregate of different kinds of minerals like feldspar, quartz, and mica, which are found in granite. Both dolomite and granite are often quarried as commodities where they are useful to industry, and the term *mineral commodity* is applied in this volume to include both rocks and minerals useful to industry. The following rock classifications include the most common types: I. Igneous rocks; II. Sedimentary rocks; III. Metamorphic rocks.

I. Igneous rocks

Volcanic rocks	Rhyolite	Andesite	Basalt
Dike rocks	Porphyritic equivalents of volcanic and granitic rocks		
Granitic rocks	Granite	Diorite	Gabbro

The more siliceous or acidic, light-colored igneous rocks comprise the rhyolite-granite class. Volcanic glasses, pumice, and perlite are in this class.

The more basic or ferromagnesian, dark-colored rocks comprise the basalt-gabbro class and the ultrabasic series of peridotites (serpentine) and pyroxenite.

II. Sedimentary rocks and their metamorphic equivalents

Unconsolidated	*Consolidated*	*Metamorphosed equivalents*
Gravel	Conglomerate	Conglomerate quartzite
Sand	Sandstone	Quartzite
Clay and silt	Shale	Slate, phyllite, or schist
Marl	Limestone and dolomite	Marble and crystalline limestone or dolomite

III. Metamorphic rocks
(High-grade metamorphism)
Various schists and gneisses formed by deep-seated alteration of either sedimentary or igneous rocks

Often the prefix *meta-* is used to indicate that the rock has been altered by deep-seated pressure and heat. Schists and gneisses may be the product of metamorphism of either sedimentary or igneous rocks.

Classification of Mineral Deposits. Concentrations of minerals, as in the case of ore deposits, have come about in many different ways and during many different geologic periods. So far as geologic processes are concerned, they may be classified in the following manner.

Classification of mineral deposits

Sedimentary deposits
  Examples: Placer deposits in streams
    Saline deposits in lakes
    Clay deposits in lagoons
    Limestone deposits in the sea
Residual deposits
  Examples: Manganese oxide deposits, concentrated by weathering
    Clay deposits, resulting from weathering
Vein and replacement deposits
  Examples: Shallow veins, such as cinnabar deposits
    Intermediate veins, such as along the Mother Lode
    Deep veins and irregular contact deposits, such as tungsten deposits, in the High Sierra
Magmatic deposits
  Examples: Pegmatite bodies, containing gem minerals
    Chromite concentrations in serpentine

The Geologic Record. Every mineral deposit represents not only the results of geologic processes, but may be considered a page in geologic history. That page is inserted in the larger chapters written in the rock formations which make up the earth's crust.

In the formation of rocks and their associated mineral deposits, a long history is involved representing time measured in millions of years. In building up any historical record of a given area, the sequence of the rock formations must first be determined through field study of stratigraphy and structure. Each rock unit is related to the history of other rocks of the earth as a whole. Through careful and extensive field and laboratory studies, various periods and ages have been established for the rocks of the earth, and it is a remarkable fact that there are rock formations in California representing practically every major age group known. The general geologic column, or time scale, is shown in table 1.

The rocks and mineral deposits are part of the internal structure of the earth, whether they occur at depth or immediately beneath the surface. The actual surface features of the earth generally reflect this internal structure, or at least the major features of it. That is why a relief model of the State of California exhibits such interesting features, which appear to be closely related to the distribution of mineral deposits.

As the mineral deposits are associated with rock structure and the rock structure is reflected in the surface relief, all these features form a pattern which cannot be haphazard but which is controlled by natural environment. Therefore, the surface features of California, as exhibited by a relief map of the state, are the results of recent geologic processes acting upon an underlying mass of rocks formed millions of years ago.

Table 1. Geologic time scale

Possible age in millions of years	*Era*	*Period*	*Epoch*
0 to 60	Cenozoic	Quaternary	Recent Pleistocene
		Tertiary	Pliocene Miocene Oligocene Eocene Paleocene
60 to 190	Mesozoic	Cretaceous Jurassic Triassic	
190 to 500	Paleozoic	Permian	
		Carboniferous	Pennsylvanian Mississippian
		Devonian Silurian Ordovician Cambrian	
500 and over	Pre-Cambrian	Algonkian Archean	

If the surface of the earth were immovable, erosion would eventually level it down to a smooth plain, but since parts of it are frequently elevated, depressed, or displaced from other parts by deep-seated action in the earth, the effect of erosion is variable. It is accelerated on the higher places, while sediment is carried to fill up the places which are lower.

In the erosional carving of rocks of different hardness and character, an irregular surface is developed reflecting the underlying structures. Where the earth has been displaced along great earthquake faults, the rocks may be so pulverized that erosional processes wear out long, narrow valleys such as those found along the great San Andreas fault.

Maps of California showing the major structural features, the distribution of principal rock types, and the relief features, show that the state may be divided into a number of different regional provinces, each of which has distinct physical characteristics. This is further brought out when these provinces are examined in the field, and the distribution of the mineral deposits is mapped in relation to rock formations, structure, and topography.

Geomorphic Provinces. The distinctive natural divisions of California fall into at least eleven well-recognized physiographic or geomorphic provinces. For the sake of describing them briefly and treating them from the standpoint of their geologic growth, these eleven provinces may be grouped into five areas with somewhat similar physical features.

Group I includes three great mountain areas—the Sierra Nevada, the Klamath Mountains, and the Peninsular Ranges. All three represent positive earth elements in the evolution of the geologic past. As mountain areas, they gave source to sediments which filled basins in the sea during Cretaceous and Tertiary periods. The basin areas were later raised above sea level and the rocks were thrown into long folds trending northwestward ; these areas, now the Coast Ranges and Transverse Ranges, form the two provinces of Group II.

Today there lies between the Sierra Nevada and Coast Ranges the Great Valley of California. This basin is filled with sediments, and is drained from the north by the Sacramento River and from the south by the San Joaquin River. These rivers join in the delta area before they enter San Francisco Bay through Carquinez Strait. Farther south is another basin filled with sediments, the surface of which, over a large area, lies below sea level. This is the Colorado Desert, including the Salton Sink. It occupies a position between the Peninsular Ranges and the mountain ranges of the Mojave Desert. The Great Valley of California and the Colorado Desert form Group III.

A large area in the northeastern part of California is covered with volcanic rocks, which extend into eastern Oregon and eastern Washington, and cover in all some 250,000 square miles. For the most part, they form a plateau which, in California, is called the Modoc Plateau. Along the western margin of the Modoc Plateau high volcanic cones rise, forming the Cascade Range. In California, this range is dominated by Mt. Shasta; Lassen Peak terminates the Cascade province at its southern extremity. The Modoc Plateau and the Cascade Range are included in Group IV.

To the east of the Sierra Nevada and the Modoc Plateau, and extending far across the State of Nevada, is a geomorphic province known as the Basin Ranges. It is characterized by block-faulted mountains, separated by gravel-washed desert valleys. A portion of this province appears in the extreme northeastern corner of California where it is known as the Warner Range, and also to the east of the Sierra Nevada. The characteristic northwest trend of the basin ranges is terminated along the great Garlock fault, which also terminates the Sierra Nevada on the south, where the Tehachapi Mountains join the Transverse Ranges. At this point, the Garlock fault intersects the San Andreas fault and the area occupying the triangle formed between these two great faults is a characteristic desert region known as the Mojave Desert. It stretches far to the east through San Bernardino County, and to the southeast through the eastern part of Riverside and Imperial Counties. The Mojave Desert may be considered to be bounded along the southwest by the San Andreas fault. The Mojave Desert and Basin Ranges, together, form Group V. The geologic features of these desert areas are very different from those of the other provinces, and very complex.

It is logical that these geographic provinces and groups of provinces, distinct as they are from each other, should contain entirely different

Geomorphic provinces of California arranged in five groups

1. Sierra Nevada	Group I
2. Klamath Mountains	
3. Peninsular Ranges (including Los Angeles Basin)	
4. Coast Ranges	Group II
5. Transverse Ranges	
6. Great Valley of California	Group III
7. Colorado Desert	
8. Modoc Plateau	Group IV
9. Cascade Range	
10. Basin Ranges	Group V
11. Mojave Desert	

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METALS

NON-METALS

OIL AND GAS
SEDIMENTS EX

EXPL

METALS INCLUDE
ANTIMONY,
GOLD, LEAD,
PYRITES, QU

NON-METALS INCLU
APATITE, A
BROMINE, C
FELDSPAR, F
TRACHYTE-ET
MAGNESITE,
WATER, NI
POTASH, SA
SODIUM SULPH
TALC, VOLC

Today there lies between the Sierra Nevada and Coast Ranges the Great Valley of California. This basin is filled with sediments, and is drained from the north by the Sacramento River and from the south by the San Joaquin River. These rivers join in the delta area before they enter San Francisco Bay through Carquinez Strait. Farther south is another basin filled with sediments, the surface of which, over a large area, lies below sea level. This is the Colorado Desert, including the Salton Sink. It occupies a position between the Peninsular Ranges and the mountain ranges of the Mojave Desert. The Great Valley of California and the Colorado Desert form Group III.

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6. Great Valley of California	Group III
7. Colorado Desert	
8. Modoc Plateau	Group IV
9. Cascade Range	
10. Basin Ranges	Group V
11. Mojave Desert	

SALIENT FEATURES OF THE GEOMORPHIC PROVINCES

By Olaf P. Jenkins

GREAT VALLEY OF CALIFORNIA

Central alluvial plain, about 50 miles wide by 400 miles long, lying between Coast Ranges and Sierra Nevada and containing a basin of interior drainage at its southern end. Drained by Sacramento and San Joaquin Rivers, which join and enter San Francisco Bay. Eastern border formed by west-sloping Sierran bedrock surface, which continues westward beneath alluvium and older sediments. Western border underlain by east-dipping Cretaceous and Cenozoic strata which form a deeply buried synclinal trough, lying beneath Great Valley along its western side. To the south, great oil fields follow anticlinal uplifts which mark the southwestern border of San Joaquin Valley and its southern basin. To the north, Sacramento Valley plain interrupted by Marysville Buttes, remnants of an isolated ancient volcano.

SIERRA NEVADA

A singular tilted fault-block of great magnitude, nearly 400 miles long, presenting high, rugged multiple scarp face on eastern front, in contrast to gentle western slope (about 2°) which disappears under sediments of Great Valley. Deep river-cut canyons down western slope, their upper courses, especially in massive granites of higher Sierra, modified by glacial sculpturing, forming such scenic features as Yosemite Valley. High continuous crest-line culminating in Mt. Whitney (elevation, 14,495.811 feet above sea level, highest point in United States) near eastern scarp. Glacial moraines and alluvial fans spreading over fault rifts and dropped blocks along eastern base of range. Metamorphic bedrock (still partly capped by Tertiary volcanics), containing gold-bearing veins, with north-south structural trend, predominant in western flank and northern end of Sierra. Northern Sierra boundary definitely marked where bedrock disappears under Cenozoic volcanic cover of Cascade Range. Southern Sierra terminated by Garlock fault, which forms northern border of Mojave Desert, and by San Andreas fault on the west where Sierra joins southern Coast Ranges.

CASCADE RANGE

Chain of volcanic cones, southern extension of province which passes through Oregon and Washington. Dominated by Mt. Shasta, glacier-mantled volcanic cone, elevation 14,162 feet above sea level. Terminated on the south by Lassen Peak, the only active volcano in the United States. Transected by deep canyons of Pit River which flows through range between these two major volcanic cones, after winding across interior Modoc Plateau on way to Sacramento River.

MODOC PLATEAU

Interior platform (elevation 4000-6000 feet above sea level), southern extension of Oregon lava plateau, consisting of thick accumulation of lava flows and tuff beds with many small volcanic cones. Occasional lakes, marshes, and sluggishly flowing streams. North-south faults in evidence. Province bounded indefinitely by Cascade Range on west and by Basin-Ranges on east and south.

KLAMATH MOUNTAINS

Complex rugged topography. Prominent peaks and ridges 6000-8000 feet above sea level. Drainage transverse and irregular developed on uplifted plateau. Entire mountain mass cut through by Klamath River. Successive benches with gold-bearing gravels on sides of canyons. Province more closely allied to Sierra Nevada than to Coast Ranges, with hard pre-Cretaceous rocks exposed by dissection. Province continues into Oregon. Volcanic rocks of Cascade Range on east boundary; Cretaceous sediments on southeast; Franciscan and younger Coast Range formations, traversed by longitudinal faults, on southwest.

COAST RANGES

System of longitudinal mountain-ranges (2000 to 4000, occasionally 6000 feet elevation above sea level) and valleys. Trend, N. 30° to 40° W., controlled by folding and faulting. Province terminated on east where strata dip beneath alluvium of Great Valley; on west by Pacific Ocean with mountains rising sharply from uplifted and terraced, wave-cut coast; on north by South Fork Mountains, which possess characteristic trend of Coast Ranges, but geology of Klamath Mountains, on south, by Transverse Ranges, differing distinctly in structural trend, but containing thick series of late Mesozoic and Cenozoic sedimentary strata in common with Southern Coast Ranges. Continuity of coastal mountain-trend cut off obliquely by open embayments and by change in general direction of coast line, especially to the north. Northern and southern ranges separated by depression of San Francisco Bay area. Continental shelf transected by many submarine canyons (Mendocino submarine scarp, probably produced by faulting; Monterey submarine canyon, 10,000 feet deep, apparently a submerged river canyon). Northern Coast Ranges dominated by irregular, knobby, landslide-topography of Franciscan formation. Contains fault valleys as yet unmapped. Eastern border characterized by strike-ridges and valleys in Upper Mesozoic strata. Volcanic cones and flows south of Clear Lake. San Francisco Bay area and southern Coast Ranges more diversified and complex, largely controlled by structure of Cenozoic, Cretaceous, and Franciscan sediments. Dominated by rift of active San Andreas fault, trend slightly oblique to adjacent ranges, total length over 600 miles from Pt. Arena to Gulf of California (displacement during 1906 earthquake horizontal, with coast side moving northward). Coast Range granitic core, extending from southern extremity of Coast Ranges to Farallon Islands, bounded by San Andreas fault on east and by Nacimiento fault zone on west.

TRANSVERSE RANGES

Complex series of mountain ranges and valleys distinguished by dominant east-west trend in contrast to NW-SE direction of Coast Ranges and Peninsular Ranges which the Transverse Ranges separate. Structural trends (NW-SE and NE-SW) subordinate to major east-west direction, significant in the formation of important oil field structures. Cenozoic sedimentary section one of the thickest in the world. Western limit of province, island group (San Miguel, Santa Rosa, and Santa Cruz Islands), eastern limit, within Mojave Desert, including San Bernardino Mts., lying on east side of San Andreas fault (trend of fault, N.60° W., a change of 20° in direction from its alignment in the Coast Ranges).

PENINSULAR RANGES

A series of ranges separated by longitudinal valleys, trending NW-SE, conditioned by erosion along faults, representing active branches of San Andreas system. Trend of topography like that of Coast Ranges, but geology more like that of Sierra Nevada, dominating rocks being granitic, intruded into older metamorphic series. Province continuous into Lower California. Bounded on east by Colorado Desert in series of right-angle jogs due to interruption of fault traces. Los Angeles Basin, and the island group (Santa Catalina, Santa Barbara, and the distinctly terraced San Clemente and San Nicolas Islands), together with surrounding continental shelf (cut by deep submarine fault troughs) included in this province.

COLORADO DESERT

A low-lying barren desert basin, in part (about 245 feet) below sea level, dominated by Salton Sea. Province a depressed block between active branches of alluvium-covered San Andreas fault with southern extension of Mojave Desert on east. Characterized by ancient beach lines and silt deposits of extinct Lake Cahuilla.

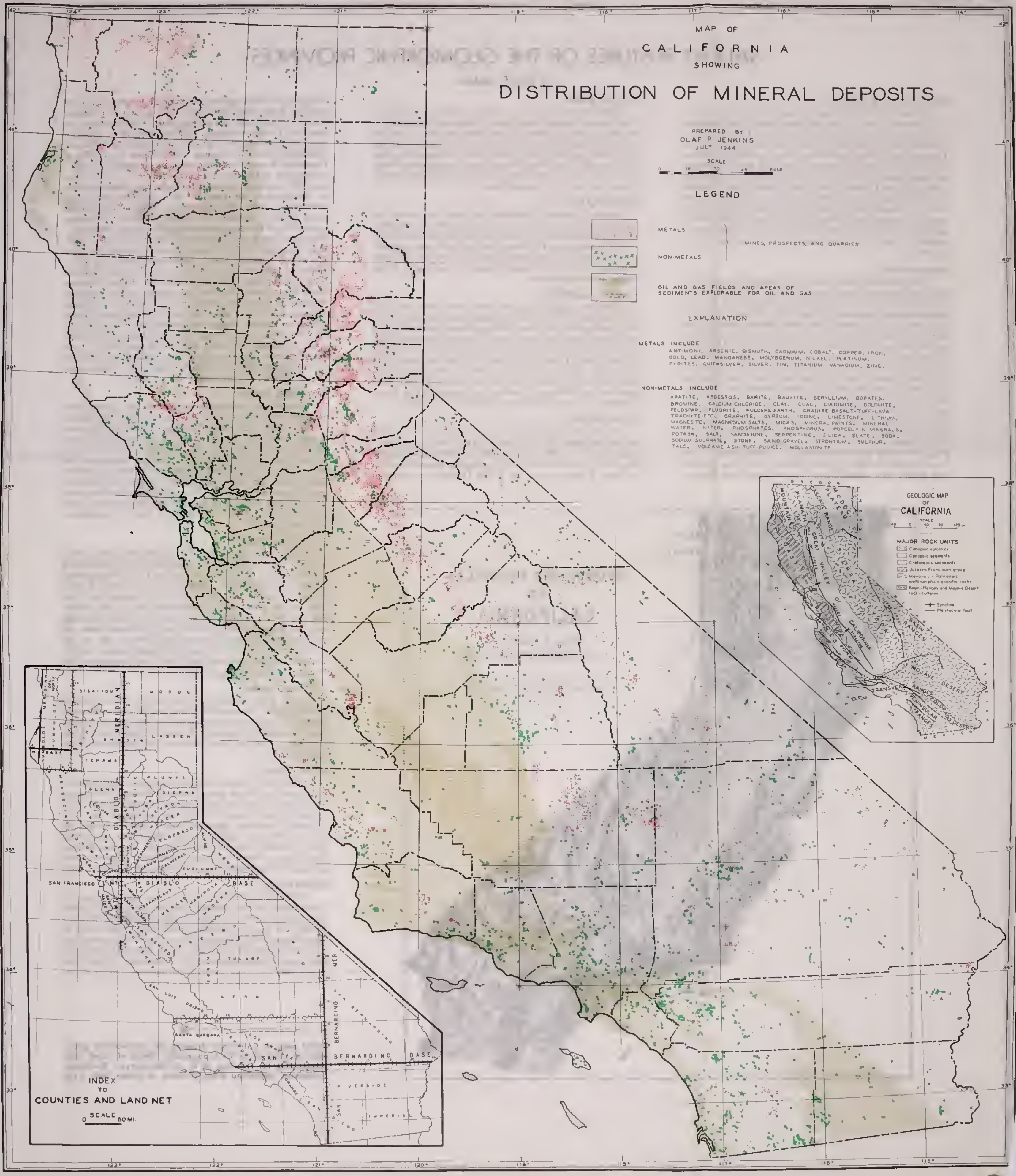
MOJAVE DESERT

Broad interior region of isolated mountain ranges separated by expanses of desert plains. Inclosed drainage with playas, except for Colorado River, bordering province on east. Two important fault trends: NW-SE, more prominent; east-west, secondary (apparent alignment with Transverse Ranges significant). Province wedged in sharp angle between Garlock fault (southern boundary Sierra Nevada) and San Andreas fault, where it bends east from major trend. Separated from prominent Basin-Ranges by eastern extension of Garlock fault.

BASIN-RANGES

Distinctly a Nevada province lying wholly within the Great Basin. Interior drainage with lakes and playas. Typical fault-block structure, made up of roughly parallel ranges alternating with basins or troughs. Death Valley, lowest area in United States (280 feet below sea level), one of these troughs or *grabens*. Another, Owens Valley, lying between bold eastern fault-scarp of Sierra Nevada and Inyo Mountains. To the north, Modoc Plateau lying between Basin-Ranges and Cascade Range.

Relief map of California showing the geomorphic provinces as related to the topography. Photo of relief map (copyright), by courtesy of H. A. Sedelmeyer, Berkeley, California, reprinted from Division of Mines Bull. 118.



MAP OF

CALIFORNIA

SHOWING

DISTRIBUTION OF MINERAL DEPOSITS

PREPARED BY
OLAF P JENKINS
JULY 1944

SCALE
0 16 32 48 64 MI

LEGEND

	METALS	MINES, PROSPECTS, AND QUARRIES.
✕	NON-METALS	
	OIL AND GAS FIELDS AND AREAS OF SEDIMENTS EXPLORABLE FOR OIL AND GAS	

EXPLANATION

METALS INCLUDE
ANTIMONY, ARSENIC, BISMUTH, CADMIUM, COBALT, COPPER, IRON, GOLD, LEAD, MANGANESE, MOLYBDENUM, NICKEL, PLATINUM, PYRITES, QUICKSILVER, SILVER, TIN, TITANIUM, VANADIUM, ZINC.

NON-METALS INCLUDE
APATITE, ASBESTOS, BARITE, BAUXITE, BERYLLIUM, BORATES, BROMINE, CALCIUM CHLORIDE, CLAY, COAL, DIATOMITE, DOLOMITE, FELDSPAR, FLUORITE, FULLERS EARTH, GRANITE-BASALT-TUFF-LAVA TRACHYTE-ETC., GRAPHITE, GYPSUM, IODINE, LIMESTONE, LITHIUM, MAGNESITE, MAGNESIUM SALTS, MICAS, MINERAL PAINTS, MINERAL WATER, NITER, PHOSPHATES, PHOSPHORUS, PORCELAIN MINERALS, POTASH, SALT, SANDSTONE, SERPENTINE, SILICA, SLATE, SODA, SODIUM SULPHATE, STONE, SAND-GRAVEL, STRONTIUM, SULPHUR, TALC, VOLCANIC ASH-TUFF-PUMICE, WOLLASTONITE.

types and kinds of mineral deposits. As a result, more mineral commodities have been developed in California than in any other area of similar extent. These are of sufficient importance to make the state nearly self-sufficient in minerals for industry. The most important mineral belts, districts, and occurrences, are grouped below by provinces and by the geologic period of their formation.

Group I

- Vein and replacement deposits of the Sierra Nevada, Klamath, and Peninsular Ranges (mineralization chiefly late Jurassic and early Cretaceous)
  - Sierra Nevada
    - Mother Lode—East Belt—Grass Valley—Nevada City—Alleghany gold-quartz district
    - Foothill copper-zinc belt and northern copper belt
    - Central-southern lead-zinc belt
    - Eastern tungsten belt
    - Southern tungsten, tin, and antimony belt
    - Chromite-bearing serpentine belts
    - Manganese-bearing cherts
    - Magnesite replacement in serpentine
  - Klamath Mountains
    - Gold belts
    - Shasta copper-zinc and iron belt
    - Chromite-bearing serpentine belts
    - Manganese-bearing cherts
    - Magnesite replacements in serpentine
  - Peninsular Ranges
    - Gold belts
    - Tin district
    - Gem-bearing pegmatite district
    - Nickel district
- Oil and gas of Los Angeles Basin chiefly of Tertiary age
- Limestone deposits of Paleozoic in all three provinces
- Placer gold—Tertiary and Quaternary—in all three provinces
- Clay, coal, and quartz sand deposits of Eocene and Paleocene (Ione and Alberhill) in all three provinces

The Klamath Mountains and Peninsular Ranges are provinces at opposite ends of the state which have many geologic features in common with those of the Sierra Nevada. The Klamath Mountains, however, contain a section of much older rocks than any found in the Sierra Nevada. The southern Peninsular Ranges contain a large area of pegmatites not present in the northern provinces, but they do not contain chromite-bearing serpentine. The orderly arrangement of mineral zones and belts in the Sierra Nevada is much more striking than in the Klamath Mountains and Peninsular Ranges.

Group II

- Coast Ranges and Transverse Ranges
  - Franciscan (Jurassic) chromite-bearing serpentine
  - Manganese-bearing Franciscan cherts
  - Magnesite replacements in serpentine
  - Quicksilver deposits in Tertiary and Quaternary
  - Small pyrite and copper deposits, and a silver district in northern Coast Ranges—Tertiary
  - Very little gold in Jurassic rocks
  - Titanium deposits in San Gabriel Transverse Ranges
  - Franciscan limestone
  - Paleozoic limestone and dolomite
  - Tertiary limestone

- Eocene coal, quartz sand
- Tertiary volcanic rocks (building stone and aggregates)
- Tertiary oil and gas fields
- Gypsite deposits in Tertiary and Quaternary rocks
- Marine diatomite of Tertiary
- Recent salines; placer gold in Transverse Ranges

In the Coast Ranges there is a central belt of old granite basement rocks, quite different from the so-called basement of Jurassic Franciscan igneous and sedimentary rocks which underlies other parts of the province. In this and other respects, the Transverse Ranges have many of the same characteristics as the southern Coast Ranges, but their structural trend is westward rather than northwestward. The large oil and gas fields of the state are grouped near each other: in the southern Coast Ranges, Transverse Ranges, Los Angeles Basin, and southern San Joaquin Valley.

Group III

- Great Valley of California
  - Oil and gas of Tertiary
  - Gas of Cretaceous
- Colorado Desert (sometimes included with group V)
  - Carbon-dioxide gas

The Great Valley is a large province enclosed by high mountains with distinct characteristics, but judged as an oil and gas province, it may be likened somewhat to the Los Angeles Basin, which lies between the Peninsular Ranges and the Transverse Ranges. The Colorado Desert is a basin filled with sediments, but these sediments are of different character than those of the Great Valley.

Group IV

- Cascade Range and Modoc Plateau
  - Pumice and perlite deposits
  - Freshwater diatomite of Tertiary

The Modoc Plateau and the Cascade Range are volcanic provinces, and represent extensions of similar provinces southward from Oregon. The volcanic rocks cover a basement which should connect the Sierra Nevada with the Klamath Mountains.

Group V

- Basin Ranges and Mojave Desert
  - Tertiary and Quaternary
    - Complex metalliferous deposits, gold and silver, etc.
    - Manganese epithermal deposits
    - Strontium, borax, and various salines
    - Sulfur and gypsum deposits
    - Gold and tungsten placers
  - Late Jurassic and early Cretaceous
    - Complex metalliferous deposits (gold, silver, lead, zinc, copper)
    - Lead and zinc of Darwin-Cerro Gordo district
    - Tungsten deposits of Bishop district
    - Iron deposits, some of doubtful age
  - Paleozoic and older
    - Limestone and some dolomite deposits
  - Pre-Cambrian
    - Talc deposits of Death Valley area
    - Rare earth metals
    - Andalusite, deposits of White Mountains
  - Age unknown
    - Rare earth metals of Clark Mountains

The Basin Ranges and the ranges of the Mojave Desert all represent a mountainous desert region which has somewhat similar geologic features, but which is quite distinct from all other sections of the state. The oldest rocks of the geologic column occur in these provinces. Marine Cretaceous and Tertiary are lacking, but much of the mineralization is Tertiary, and some is much earlier.

Influence of Earth Sciences on Mineral Development. A broad knowledge of the geology, physiography, and history of California is essential in the discovery, development, and utilization of the mineral resources of the state. Even future economic trends can be predicted with greater success, if these features are carefully and continually studied and the facts scientifically weighed and placed in systematic order. For these reasons, the Division of Mines has embarked on extensive statewide studies of the geology of mineral deposits.

In another forthcoming volume, it is the intention of the Division of Mines to record the extensive uses which the industries make of these minerals, and the specifications required. The subject of markets for raw mineral materials may then become better understood by the owners of the mineral deposits, while the user of minerals should become better acquainted with the extensive resources of the State of California. As a result, more of the available minerals of California may be used in preference to those now imported, with a saving to industry and a greater prosperity for the producer.

PART I

SUMMARY OF MINERAL WEALTH IN CALIFORNIA FOR 1948

CONTENTS

MINERAL PRODUCTION IN CALIFORNIA DURING 1948 COMPARED WITH 1947

By Henry H. Symons, Fenelon F. Davis, and Charles V. Averill

The total value of the mineral output in California during 1948 reached an all-time high and passed the billion dollar mark for the first time in history. The total value of the California mineral output for the year 1948 was $1,174,674,000, compared with the 1947 total value of $859,039,000, as compiled by the U. S. Bureau of Mines. The large increase in the total value of the state's 1948 mineral output, $315,635,000, resulted chiefly from a general price increase in all grades of petroleum. This general price increase was maintained throughout the entire 1948 production year. A total of 53 commercial mineral substances was produced during 1948, and all 58 counties of the state contributed to this production.

Antimony. During 1948 the Rocket mine in Inyo County shipped five tons of antimony concentrates valued at $1,467. This is the only antimony shipment reported since 1944, when three properties (one each in Inyo, San Bernardino, and Riverside Counties) reported shipments of 14 tons of antimony concentrates.

The average price of antimony metal in 1948 was 36.67 cents per pound in car lots, New York, compared with 33.45 cents per pound in 1947, according to U. S. Bureau of Mines Minerals Yearbook. The Yearbook of the American Bureau of Metal Statistics reported the 1948 New York average price of antimony as 38.168 cents per pound, compared with 34.852 cents per pound in 1947, and 17.306 cents per pound in 1946.

Asbestos. Asbestos was shipped during 1948 from three properties in Shasta County. All this production was of the amphibole variety. The 1947 output came from two properties in Shasta County and one property in Placer County.

Native Asphalt (Bituminous Rock). No shipments of bituminous rock were reported in 1948 from California deposits. This is the first year since 1887 that no production was reported. The rock quarried in 1947 came from a large deposit in Santa Cruz County which has been the principal producer for many years. The plant was dismantled in 1948.

Barite. The barite shipped in California during 1948 came from a single property in Mariposa County. The 1947 output came from two properties, one in Mariposa County, and one in Plumas County.

Boron Minerals. Shipments of borates from California deposits during 1948 totaled 450,932 short tons valued at $11,147,735, and came from two properties in Inyo County, two properties in San Bernardino County, and a single property in Kern County. The 1948 output showed a decrease in both quantity and value as compared with the 1947 production of 501,935 short tons worth $11,844,108. The 1947 output was the largest annual production so far reported in the state. The above figures include: sodium borates (kernite and kramerite) from Kern County; crystallized borax from the brines of Searles Lake in San Bernardino County and Owens Lake in Inyo County; and a small amount of colemanite from Death Valley, Inyo County.

Bromine. The bromine produced in California during 1948 was recovered from sea-water bitterns obtained from the salt works in Ala-

Table 1. Quantity and value of mineral substances produced in California during 1946, 1947, and 1948.

The following figures for the 3 years 1946, 1947, and 1948 are supplied by the United States Bureau of Mines, with which the California State Division of Mines has a cooperative agreement for the collection of these statistics, starting with the year 1947.

Mineral product		1946		1947		1948	
		Quantity	Value	Quantity	Value	Quantity	Value
Antimony ore (concentrates)	short tons	----------	----------	----------	----------	5	$1,467
Arsenious oxide	do	[1]	[1]	[1]	[1]	[1]	[1]
Asbestos	do	[2]	[2]	[2]	[2]	[2]	[2]
Asphalt (native)	do	[2]	[2]	[2]	[2]	----------	----------
Barite	do	[2]	[2]	[2]	[2]	[2]	[2]
Boron minerals	do	430,689	$9,575,866	501,935	$11,844,108	450,932	11,147,735
Bromine	pounds	[2]	[2]	[2]	[2]	[2]	[2]
Calcite (iceland spar)	do	[2]	[2]	[3]	[3]	[3]	[3]
Calcium chloride	short tons	9,979	170,994	7,968	111,950	10,009	167,610
Cement	barrels	20,173,231	33,906,675	22,846,458	46,539,749	24,162,926	57,742,226
Chromite	short tons	[2]	[2]	948	[2]	274	[2]
Clay:							
Products, heavy clay (other than pottery and refractories):		----------	[4] 12,175,000	----------	[4] 16,793,000	----------	[4] 21,600,000
Raw	short tons	[5] 1,670,305	[5] 2,254,164	[5] 1,950,076	[5] 2,965,360	[5] 2,673,877	[5] 3,813,329
Coke	do	260,470	[2, 6]	332,244	[2, 6]	296,749	[2, 6]
Copper	pounds	8,480,000	1,373,760	4,814,000	1,010,940	962,000	208,754
Diatomite	short tons	[2]	[2]	[2]	[2]	[2]	[2]
Feldspar (crude)	long tons	----------	----------	[2]	[2]	[2]	[2]
Ferro-alloys	short tons	7,414	[2, 6]	5,278	[2, 6]	[2, 6]	[2, 6]
Fuller's earth	do	[2]	[2]	[2]	[2]	[2]	[2]
Gem stones		----------	[2]	----------	[3]	----------	[2]
Gold	troy ounces	356,824	12,488,810	431,415	15,099,525	421,473	14,751,555
Gypsum (crude)	short tons	574,345	1,315,699	811,798	1,996,157	962,038	2,354,390
Iodine	pounds	[2]	[2]	[2]	[2]	[2]	[2]
Iron:							
Ore	long tons	226,062	[2]	373,574	[2]	345,863	[2]
Pig	short tons	344,024	[2, 6]	453,376	[2, 6]	375,113	[2, 6]
Kyanite	do	[2]	[2]				
Lead	do	9,923	2,163,214	10,080	2,903,040	9,110	3,261,380
Lime	do	172,623	2,144,712	181,296	2,615,599	179,257	3,026,941
Lithium minerals	do	[2]	[2]	[2]	[2]	[2]	[2]
Magnesite	do	[2]	[2]	[2]	[2]	[2]	[2]
Magnesium	do	56	21,664	----------	----------	----------	----------
Magnesium compounds (from sea water)[7] equivalent	short tons MgO	55,953	2,814,979	40,000	2,161,000	38,500	2,549,000
Mercury	flasks (76 pounds)	17,782	1,746,904	17,165	1,437,397	11,188	855,770
Mica, scrap	short tons	[2]	[2]	[2]	[2]	----------	----------

Mineral waters	gallons sold	[2]	[3]	[2]	[2]	[2]	
Molybdenum	pounds	[2]	[2]	[2]	[2]	[2]	[2]
Natural gas (estimated value at wells)	M cubic feet	487,904,000	36,056,000	560,510,000	57,284,000	570,954,000	64,803,000
Natural gasoline and allied products:							
Natural gasoline and cycle products	gallons	734,227,000	32,085,000	833,473,000	46,302,000	842,425,000	69,578,000
Liquefied petroleum gases	do	176,311,000	4,933,000	230,635,000	7,901,000	269,644,000	16,961,000
Ores (crude), etc.:							
Copper	short tons	86,297	[8]	15,993	[8]	152	[8]
Dry and siliceous (gold and silver)	do	335,657	[8]	449,792	[8]	424,227	[8]
Lead	do	57,330	[8]	87,913	[8]	22,005	[8]
Zinc	do	45,043	[8]	49,651	[8]	5,233	[8]
Zinc-copper	do	99,176	[8]	35,745	[8]		
Zinc-lead	do	4,264	[8]	9,695	[8]	75,159	[8]
Peat	do	8,137	105,242	[2]	[2]	6,942	33,265
Pebbles for grinding	do	74	927	[2]	[2]	[2]	[2]
Perlite	do					[2]	[2]
Petroleum	barrels	314,713,000	387,100,000	333,132,000	572,990,000	340,089,000	823,696,000
Platinum metals (crude)	troy ounces	67	[2]	324	[2]	272	[2]
Potassium salts	short tons	[2]	[2]	[2]	[2]	[2]	[2]
Pumice	do	89,181	755,570	169,037	1,026,275	196,934	1,110,447
Pyrites	long tons	[2]	[2]	[2]	[2]	[2]	[2]
Quartz	short tons	[2]	[2]	[2]	[2]	[2]	[2]
Salt (sodium chloride)	do	729,092	3,358,060	768,397	3,810,898	914,035	3,927,722
Sand and gravel	short tons	27,220,849	18,396,460	31,386,826	25,338,967	33,786,520	30,592,965
Sand and sandstone (ground)	do	[2]	[2]	[2]	[2]	[2]	[2]
Silver	troy ounces	1,342,651	1,084,862	1,597,442	1,445,685	724,771	655,954
Slate			[2]		[2]		[2]
Sodium carbonate	short tons	215,625	3,427,086	293,051	5,862,178	288,769	6,623,280
Sodium sulfate	do	[2]	[2]	[2]	[2]	[2]	[2]
Stone	do	[9] 8,950,320	[9] 8,452,083	[9] 12,757,790	[9] 13,012,556	[9] 11,936,240	[9] 13,155,454
Strontium minerals	do	243	3,726				
Sulfur ore	long tons	757	11,835	698	9,074	[2]	[2]
Sulfuric acid (basis, 100 percent)[10]	short tons	[2, 8]	[2, 8]	[2, 8]	[2, 8]	[2, 8]	[2, 8]
Talc, pyrophyllite, and ground soapstone	short tons	78,170	1,434,978	91,537	1,595,422	98,681	1,773,764
Titanium concentrates:							
Ilmenite	do					[2]	[2]
Tungsten concentrates (60 percent WO_2 basis)	do	1,262	1,117,855	394	548,233	1,767	[2]
Zinc	do	6,877	1,677,988	5,415	1,310,430	5,325	1,416,450
Miscellaneous [11]			21,909,443		29,565,251		41,595,712
Total value, eliminating duplications			$592,294,000		$859,039,000		$1,174,674,000

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[1] Figure not available.

[2] Value included with Miscellaneous.

[3] No canvass.

[4] Figure obtained through cooperation with Bureau of the Census.

[5] Sold or used; value of clay used in cement and heavy clay products is included here but is not included in total value for state.

[6] Value not included in total value for state.

[7] Comprises all compounds from raw sea water and bitterns. Data for 1946 are not quite comparable with 1947-48 in that the former are on a gross-weight basis and include some compounds made from dolomite in combination with sea water. Figures for 1947-48 are partly estimated.

[8] Not valued as ore; value of recoverable-metal content included with the metals.

[9] Exclusive of marble in 1946-47 and of dimension basalt in 1948, values for which are included with Miscellaneous.

[10] From lead smelting.

[11] Includes minerals indicated by "2" and "9" above.

meda County on San Francisco Bay, and from the brines of Searles Lake in San Bernardino County.

Calcium Chloride. The calcium chloride produced in California during 1948 totaled 10,009 short tons valued at $167,610 and came from deposits on Bristol Lake near Amboy, San Bernardino County. The 1948 output showed an increase in quantity and value over the 1947 production of 7,968 short tons worth $111,950.

Carbon Dioxide (Natural). Carbon dioxide was produced in California during 1948 from wells near Niland, Imperial County, and from wells near Hopland and Ukiah in Mendocino County. The carbon-dioxide gas from Imperial County in 1948 totaled 150,780[1] M cubic feet compared with 179,770[1] M cubic feet in 1947. Most of this natural carbon-dioxide was used in the manufacture of dry ice.

Cement. The cement produced in California during 1948 came from three mills in San Bernardino County and one mill in each of the following counties: Calaveras, Kern, Los Angeles, Riverside, San Benito, San Mateo, Santa Clara, and Santa Cruz. The 1948 output totaled 24,601,892 barrels compared with 22,788,173 barrels in 1947. Shipments from 11 California mills amounted to 24,162,926 barrels worth $57,742,226 in 1948, compared with 22,846,458 barrels worth $46,539,749 in 1947. The 1948 annual capacity of the state's cement mills was 29,170,000 barrels. In 1948, as in 1947, California led all states in the consumption of cement, and ranked second in cement production.

Chromite. The chromite shipped in California during 1948 came from a single property in Del Norte County and totaled 274 short tons, compared with 948 short tons in 1947 from properties in Butte and Del Norte Counties.

Clay. The clay, used or sold in California during 1948, totaled 2,673,877 short tons valued at $3,813,329, as compared with 1,950,076 short tons worth $2,965,360 in 1947. Of the 1948 clay production 25,562 short tons worth $352,538 was kaolin, which came from properties in Kern, Orange, and San Bernardino Counties; 547,330 short tons worth $1,312,430 was fire clay, which came from properties in Amador, Calaveras, Kern, Orange, Placer, Riverside, Sacramento, Santa Clara, and Stanislaus Counties; 18,676 short tons worth $101,450 was bentonite, which came from properties in Inyo, San Benito, San Bernardino, and San Diego Counties; and 2,082,309 short tons worth $2,046,911 was mis-

Value of heavy clay products production (other than pottery and refractories) in California during 1947 and 1948, by counties.

County	1947 value	1948 value
Alameda	$1,165,000	$1,342,000
Los Angeles	10,936,000	14,791,000
Sacramento	340,000	368,000
San Joaquin	291,000	274,000
Santa Clara	1,201,000	1,271,000
Contra Costa, Fresno, Humboldt, Kern, Orange, Placer, Riverside, San Diego, San Luis Obispo, Santa Barbara *	2,860,000	3,554,000
Totals	$16,793,000	$21,600,000

* Combined to conceal output of plants in each county.

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[1] Figures from California State Division of Oil and Gas.

cellaneous clay, which came from properties in Alameda, Calaveras, Contra Costa, Fresno, Humboldt, Kern, Los Angeles, Marin, Orange, Placer, Riverside, Sacramento, San Bernardino, San Diego, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Sutter, Tulare, and Ventura Counties.

Heavy clay products (other than pottery and refractories) produced in California had a total value of $21,600,000, as compared with a total value of $16,793,000 in 1947, and came from plants in 15 counties.

Coal. During 1948 a small amount of lignite was produced from a mine at Ione, Amador County, and was sent to a plant for the extraction of mountain wax. This is a hard wax which can be substituted for carnauba wax in such manufactured products as shoe polish and carbon paper.

Copper. The copper produced in California during 1948 totaled 962,000 pounds valued at $208,754, as compared with 4,814,000 pounds worth $1,010,940 in 1947. Most of the copper produced during 1948 was a by-product from ores mined for other metals. Copper concentrates from the Pine Creek mine of the United States Vanadium Corporation in Inyo County were a by-product from ores mined for tungsten, and accounted for more than 40 percent of the state's 1948 copper output.

Mine production of copper in California during 1948, by counties.

County	Pounds	Value
Alpine	6,000	$1,302
El Dorado	72,000	15,624
Inyo	598,000	129,766
Madera	10,000	2,170
San Bernardino	118,000	25,606
Shasta	156,000	33,852
Sierra	2,000	434
Totals	962,000	$208,754

Diatomite. The diatomite shipped in California during 1948 came from single properties in Inyo, Los Angeles, and Santa Barbara Counties. California leads the states of the nation in the production of diatomite.

Feldspar. During 1948 the feldspar shipped in California came from properties in Kern and San Bernardino Counties, whereas that shipped in 1947 came from a single property in Madera County.

Gold. The 1948 California gold output totaled 421,473 fine ounces worth $14,751,555, as compared with 431,415 fine ounces worth $15,099,525 in 1947. Gold was produced from 35 counties in 1948; 241 lode mines produced 135,917 fine ounces worth $4,757,095, and 195 placer mines produced 285,556 fine ounces worth $9,994,460.

Sacramento County led the counties in value of gold yield for 1948 with a total of $4,135,320; Nevada County was second with a total value of $3,563,385; Yuba County was third with $2,022,615, and was followed in turn by Butte, Siskiyou, Merced, Stanislaus, Shasta, Sierra, Trinity, Mariposa, and Amador Counties. The gold from Nevada, Sierra and Amador Counties was chiefly from lode mines; the gold from the other counties listed above came from placers.

The following quotation from Merrill [2] gives an outline of the activity in the gold mining industry:

> "California.—California was the leading gold-producing area in the United States in 1948, by virtue of the default of Utah owing to the year-end work stoppage at the Utah Copper mine that curtailed output to probably 50,000 ounces under expectations. California lode and placer mines yielded 421,473 ounces or a little less than in 1947. It appears that placer mines contributed approximately 70 percent of the 1948 output and lode mines 30 percent. As in 1947 the major part of the placer output came from connected bucket dredges. Leading producers of gold by dredging were the Yuba Consolidated Gold Fields, which operated dredges in the Yuba River district, Yuba County, in Butte County, and in Siskiyou County, and the Natomas Company, which operated a fleet of dredges in the Folsom district, Sacramento County. Dragline dredges were used extensively in 1948, as in 1947, but hydraulic and drift mines were worked intermittently only during the year.
>
> "The resumption of operations by the Central Eureka Mining Co., in the Mother Lode district of Amador County, idle since 1942, was a highlight in lode mining in 1948. The Grass Valley-Nevada Ctiy district, Nevada County, continued to be the leading gold-producing area; the Idaho-Maryland Mines Corp. and the Empire Star Mines Co., Ltd., properties—the latter worked by lessees—yielded approximately two-thirds of the State gold derived from gold ore."

Mine production of gold in California, 1948, by counties.

County	Mines producing [1]		Fine ounces	Value
	Lode	Placer		
Alpine	2	----------	8	$280
Amador	8	6	6,614	231,490
Butte	1	15	26,137	914,795
Calaveras	18	5	1,196	41,860
Colusa	1	----------	2	70
El Dorado and Humboldt [2]	10	6	2,666	93,310
Imperial	4	----------	171	5,985
Inyo and Fresno [2]	36	3	2,055	71,925
Kern	32	4	6,176	216,160
Lassen	2	----------	121	4,235
Los Angeles	1	2	215	7,525
Madera and Merced [2]	1	5	19,279	674,765
Mariposa	16	5	7,525	263,375
Modoc	1	----------	141	4,935
Mono	6	----------	63	2,205
Monterey	2	----------	24	840
Napa	1	----------	2	70
Nevada	13	19	101,811	3,563,385
Placer	7	17	1,330	46,550
Plumas	3	13	699	24,465
Riverside	3	----------	4	140
Sacramento	----------	12	118,152	4,135,320
San Bernardino and San Joaquin [2]	28	4	3,447	120,645
San Diego	3	----------	8	280
Shasta and Stanislaus [2]	9	8	24,938	872,830
Sierra	6	14	10,430	365,050
Siskiyou	11	30	21,226	742,910
Trinity	3	19	7,930	277,550
Tuolomne	12	2	1,314	45,990
Yuba	1	6	57,789	2,022,615
Totals: 1948	241	195	421,473	$14,751,555
1947	210	210	431,415	$15,099,525

[1] Excludes itinerant prospectors, snipers, high-graders, and others who gave no evidence of legal right to property.

[2] Combined to avoid disclosure of individual output.

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[2] Merrill, Charles White, Mine production of gold in the United States in 1948: U. S. Bur. Mines, Mineral Market Rept., Ms. 1689.

Gypsum. Crude gypsum shipped from California deposits during 1948 totaled 962,038 short tons valued at $2,354,390, as compared with 811,798 short tons worth $1,996,157 in 1947. The 1948 output was the largest in both quantity and value ever reported in the state. Of the total 1948 gypsum production, 394,979 short tons [3] was used in agriculture as a soil conditioner. The material produced in Fresno, Kern, and Kings Counties was almost entirely used for this purpose.

Gypsum production in California during 1948, by counties.

County	Short tons	Value
Fresno	15,443	$23,271
Kern	271,908	414,233
Imperial, Kings, Riverside, and Ventura	674,687	1,916,886
Totals	962,038	$2,354,390

Iodine. Two companies produced iodine in California during 1948. The iodine is extracted at four plants in Los Angeles County from waste water produced by oil wells of the Los Angeles Basin. California is the only state in the nation in which iodine is recovered.

Iron. During 1948 a total of 345,863 long tons of iron ore was shipped in California from the Eagle Mountains mine in Riverside County, and the Cave Canyon and Vulcan mines in San Bernardino County, as compared with 373,574 long tons from the same mines in 1947.

Pig iron produced in California during 1948 totaled 375,113 short tons, as compared with 453,376 short tons in 1947.

Lead. The lead production in California during 1948 totaled 18,220,000 pounds valued at $3,261,380, as compared with 20,160,000 pounds worth $2,903,040 in 1947. The Anaconda Copper Mining Company's Darwin mine in Inyo County was the largest lead producer, followed by their Shoshone mine at Tecopa in the same county. The value of the 1948 output was the largest on record, although the quantity of production was exceeded in 1917, 1946, and 1947.

The average price paid to the miners for lead during 1948 was 17.9 cents per pound, as compared with 14.4 cents a pound in 1947, and 10.9 cents per pound in 1946.

Mine production of lead in California during 1948, by counties.

County	Pounds	Value
Calaveras	2,000	$358
Inyo	17,240,000	3,085,960
Mono	4,000	716
Riverside	2,000	358
San Bernardino	838,000	150,002
Shasta	106,000	18,974
Sierra	28,000	5,012
Totals	18,220,000	$3,261,380

Lime. The lime manufactured in California during 1948 totaled 179,257 short tons, valued at $3,026,941, as compared with 181,296 short tons worth $2,615,599 in 1947. The 1948 output came from three plants in

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[3] Fertilizing materials: California Dept. Agr., Special Pub. 231, 1948.

San Bernardino County which produced 27,393 short tons of lime worth $405,411; two plants in El Dorado County; and one plant each in Alameda, Monterey, and Tuolumne Counties.

During 1948 California agriculture[4] consumed 10,927 short tons of by-product lime; 1,130 tons of hydrated lime; and 12,697 tons of limestone, shells, and marl. These materials were used on the soil to correct acidity, to assist in granulation or breaking up of heavy clay soils, to promote decay of organic substances and to assist in the formation of calcium nitrate. Pulverized limestone used as a diluent or admix in commercial fertilizers is not included in the above figures.

Lithium Minerals. Lithium-sodium phosphate was produced from the brines of Searles Lake, San Bernardino County, during 1948. This was the chief source of the nation's lithium.

Magnesite. The magnesite mined in California during 1948 came from a single property in Santa Clara County.

Magnesium Compounds from Sea Water. During 1948 a total of 38,500 short tons of MgO equivalent worth $2,549,000 was produced in California from properties in Alameda, Monterey, San Diego, and San Mateo Counties. The 1947 output was 40,000 short tons MgO equivalent, worth $2,161,000.

Mercury (Quicksilver). The California output of mercury for 1948 totaled 11,188 flasks of 76 pounds each, valued at $855,770, and came from properties in Del Norte, Lake, Napa, San Benito, San Luis Obispo, Santa Clara, Sonoma, and Yolo Counties. The 1948 production showed a decrease in both quantity and value as compared with 1947, when 17,165 flasks worth $1,437,397 was produced from properties in Fresno, Lake, Napa, San Benito, San Luis Obispo, Santa Clara, Sonoma and Yolo Counties. California accounted for 78 percent of the nation's total quicksilver output in 1948.

Mica. No sericite mica was mined during 1948 from the property near Ogilby, Imperial County, which had been producing since 1929.

Natural Mineral Pigments. A property near Ludlow, San Bernardino County, mined and shipped mineral pigment material during 1948. The output of this property has been small.

Mineral Water. Water from many springs and artesian wells, bottled and in part artificially carbonated, is classed as mineral water. Health and pleasure resorts are located at many hot springs in California. The water at some of the hot springs is not suitable for drinking, but is utilized for bathing. Counties from which mineral waters are bottled and sold are Butte, Calaveras, Contra Costa, Lake, Los Angeles, Marin, Napa, Orange, Riverside, San Benito, San Bernardino, San Diego, San Francisco, San Luis Obispo, Santa Barbara, Shasta, Siskiyou, Sonoma, and Tehama.

Molybdenum. The California output of molybdenum concentrates in 1948 came from the Pine Creek mine of the U. S. Vanadium Corporation near Bishop, Inyo County, as a by-product from tungsten ores.

Natural Gas. Natural gas produced in California during 1948 was second only to petroleum in value. Total production was 570,954,000 M cubic feet valued at $64,803,000 at the well, as compared with 560,510,000 M cubic feet worth $57,284,000 in 1947. The 1948 output came from wells in 20 counties and was the largest in quantity and value of any year on

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[4] Fertilizing materials: California Dept. Agr., Special Pub. 231, 1948.

record. The average amount received for natural gas at the well in 1948 was 11.35 cents per M cubic feet, compared with 10.22 cents per M cubic feet in 1947 and 7.4 cents per M cubic feet in 1946.

Natural-gas production in California during 1947 and 1948, by counties.

County	1947		1948	
	M. cu. ft.	Value	M. cu. ft.	Value
Fresno	65,636,000	$6,943,000	69,644,000	$7,224,000
Kern	88,753,000	8,566,000	84,803,000	8,414,000
Kings	41,113,000	4,404,000	40,310,000	4,545,000
Los Angeles	98,435,000	8,586,000	102,783,000	11,588,000
Orange	30,238,000	2,535,000	30,844,000	3,338,000
Sacramento	74,964,000	8,595,000	81,791,000	10,874,000
San Joaquin	9,926,000	1,297,000	8,277,000	1,313,000
Santa Barbara	18,586,000	1,355,000	20,329,000	1,925,000
Solano	67,278,000	8,388,000	66,212,000	8,746,000
Tulare	*	*	10,672,000	1,465,000
Ventura	47,457,000	4,517,000	46,023,000	4,359,000
Butte, Contra Costa, Glenn, Humboldt, Madera, Stanislaus, Sutter, Tulare, Yolo *	18,124,000	2,098,000	------	-------
Butte, Contra Costa, Glenn, Humboldt, Madera, Sonoma, Stanislaus, Sutter, Yolo *	------------	------------	9,266,000	1,012,000
Totals	560,510,000	$57,284,000	570,954,000	$64,803,000

* Combined to conceal the output of individual operators.

Natural-Gas Gasoline. Natural-gas gasoline produced in California during 1948 came from plants operating in the oil fields of Fresno, Kern, Kings, Los Angeles, Orange, Santa Barbara, and Ventura Counties and totaled 842,425,000 gallons valued at $69,578,000, as compared with 833,473,000 gallons worth $46,302,000 in 1947.

Natural-gas gasoline production in California during 1947 and 1948, by counties.

County	1947		1948	
	Gallons	Value	Gallons	Value
Fresno	*75,488,000	$3,990,000	*26,623,000	$2,199,000
Kern	134,520,000	6,839,000	143,654,000	11,865,000
Kings	*63,534,000	3,512,000	*116,075,000	9,587,000
Los Angeles	299,343,000	16,098,000	313,871,000	25,923,000
Orange	114,894,000	5,974,000	115,378,000	9,529,000
Santa Barbara	36,059,000	1,881,000	24,987,000	2,064,000
Ventura	109,635,000	8,008,000	101,837,000	8,411,000
Totals	833,473,000	$46,302,000	842,425,000	$69,578,000

* Natural-gas gasoline processed in Kettleman Hills oil field comes from properties in both Kings and Fresno Counties. Such production is here assigned to Kings County because figures by counties are not available.

Peat. During 1948 a total of 6,942 short tons of peat worth $33,265 was reported shipped from California properties in Contra Costa, Orange, and San Diego Counties. The 1947 data were combined to conceal the output of individual producers.

Pebbles for Grinding. Pebbles for grinding have been produced in small quantities in California since 1915. Most of this production was obtained from the beaches of San Diego County. The 1948 output was reported from Encinitas Beach, San Diego County.

Perlite. During 1948 perlite was reported shipped from a property in Napa County.

Petroleum. California ranked second among the states in quantity and value of petroleum output during 1948. The 1948 production of crude oil in California was 340,089,000 barrels worth $823,696,000, and was the largest in amount and value ever produced in the state. The 1947 yield totaled 333,132,000 barrels valued at $572,990,000.

Prices quoted on California crude oils did not change between December 27, 1947, and January 25, 1949. The prices posted in December 1947 were in effect all year with only a few minor changes.

Petroleum production in California during 1947 and 1948, by counties.

County	1947		1948	
	Barrels	Value	Barrels	Value
Fresno	44,137,000	$75,560,000	45,841,000	$111,920,000
Kern	106,058,000	176,761,000	105,426,000	253,636,000
Kings	7,504,000	15,517,000	6,551,000	17,965,000
Los Angeles	91,897,000	164,496,000	91,096,000	223,002,000
Orange	34,149,000	58,407,000	38,217,000	91,929,000
San Luis Obispo	*	*	460,000	1,208,000
Santa Barbara	22,465,000	33,297,000	23,756,000	51,992,000
Ventura	26,860,000	48,861,000	28,617,000	71,790,000
Monterey, San Bernardino, San Luis Obispo, Santa Clara*	62,000	91,000	----------	----------
Monterey, San Benito, San Bernardino, Santa Clara, Sonoma*	----------	----------	125,000	254,000
Totals	333,132,000	$572,990,000	340,089,000	$823,696,000

* Combined to conceal the output of individual operators.

Liquefied Petroleum Gases. Liquefied petroleum gases produced in California during 1948 came from plants in Fresno, Kern, Kings, Los Angeles, Orange, Santa Barbara, and Ventura Counties and totaled 269,644,000 gallons valued at $16,961,000, as compared with 230,635,000 gallons worth $7,901,000 in 1947.

Liquefied petroleum gases production in California during 1947 and 1948, by counties.

County	1947		1948	
	Gallons	Value	Gallons	Value
Fresno	*41,170,000	$1,642,000	*22,262,000	$1,400,000
Kern	90,458,000	3,452,000	107,801,000	6,781,000
Kings	*36,525,000	1,317,000	*66,480,000	4,182,000
Los Angeles	16,036,000	491,000	19,982,000	1,257,000
Orange	4,472,000	145,000	9,785,000	615,000
Santa Barbara	1,523,000	51,000	8,419,000	530,000
Ventura	40,451,000	803,000	34,915,000	2,196,000
Totals	230,635,000	$7,901,000	269,644,000	$16,961,000

* Liquefied petroleum gases processed in Kettleman Hills oil field came from gas produced in both Kings and Fresno Counties. Such production is here assigned entirely to Kings County because figures by counties are not available.

Platinum-Group Metals. The output of platinum-group metals in California during 1948 totaled 272 fine ounces and came from gold-placer operations in Butte, Mariposa, Merced, Sacramento, San Joaquin, Shasta, Siskiyou, and Yuba Counties. The 1947 output of platinum-group metals totaled 324 fine ounces and came from gold-placer properties in Butte, Merced, Sacramento, and Yuba Counties.

Potash. Potassium salts were recovered in California during 1948 by the American Potash and Chemical Company from the brines of Searles Lake, San Bernardino County.

Pumice, Pumicite, and Scoria. During 1948 a total of 196,934 short tons of pumice, pumicite, and scoria worth $1,110,447 was shipped from California deposits, as compared with 169,037 short tons worth $1,026,275 in 1947.

The material produced from Calaveras, Contra Costa, Modoc, and San Bernardino Counties and part of the production from Inyo, Kern, Madera, Mono, Napa, and Siskiyou Counties was pumice; production from Amador, San Luis Obispo, and Stanislaus Counties, and some production from Inyo, Kern, Madera, and Napa Counties was pumicite or volcanic ash; part of the production from Mono and Siskiyou Counties was scoria. The 1948 output was the largest ever reported in the state. California was the leading state in the production of these materials in 1948.

Pumice, pumicite, and scoria production in California during 1948, by counties.

County	Short tons	Value
Madera	8,311	$82,719
Modoc	14,165	79,095
Mono	8,582	257,335
Siskiyou	35,577	173,136
Stanislaus	2,066	3,840
Amador, Calaveras, Contra Costa, Inyo, Kern, Napa, San Bernardino, San Luis Obispo*	128,233	514,322
Totals	196,934	$1,110,447

* Combined to conceal the output of individual producers.

Pyrites. The 1948 production of pyrites in California came from the Hornet mine at Matheson, Shasta County. This property has been the chief source of the state's pyrites for many years.

Salt. The salt produced in California during 1948 totaled 914,035 short tons worth $3,927,722, as compared with 768,397 short tons worth $3,810,898 in 1947. Of the 1948 salt output, 633,108 short tons worth $3,091,370 came from Alameda County and the remainder came from properties in Kern, Monterey, Orange, San Bernardino, and San Diego Counties. The 1948 salt yield was the largest in both quantity and value of any year so far reported in this state.

Sand and Gravel. Sand and gravel output in California during 1948 totaled 33,786,520 short tons valued at $30,592,965, as compared with 31,386,826 short tons worth $25,338,967 in 1947. Sand and gravel production was reported from every county in the state with the exception of Alpine and San Francisco Counties.

Serpentine. Serpentine has been quarried in California for use as a building stone (verde antique), as an admix in concrete, and as a source of magnesium in the manufacture of epsom salts. Since 1946 it has also

Sand and gravel production in California during 1948, by counties.

County	Tons	Value
Alameda	3,896,600	$4,026,285
Amador	34,490	65,476
Butte	148,990	192,798
Calaveras	113,871	204,507
Colusa	65,711	20,685
Contra Costa	372,013	252,229
Fresno	932,804	1,022,024
Humboldt	359,243	293,016
Imperial	488,277	[2]
Inyo	105,176	111,937
Kern	581,495	663,945
Lake	125,008	[2]
Los Angeles	11,909,517	8,085,435
Madera	26,399	19,040
Mariposa	17,127	13,331
Modoc	114,018	61,394
Monterey	808,160	1,525,600
Napa	37,670	32,600
Orange	908,737	813,411
Plumas	18,300	8,450
Riverside	802,621	482,844
Sacramento	1,453,173	1,353,347
San Bernardino	1,671,019	1,560,323
San Diego	1,395,701	1,829,989
San Joaquin	1,679,808	1,617,023
San Luis Obispo	165,064	205,053
Santa Barbara	185,629	[2]
Santa Clara	457,451	[2]
Shasta	490,722	440,953
Sierra	33,000	11,550
Stanislaus	364,719	454,660
Trinity	8,845	12,025
Tulare	236,646	290,205
Ventura	664,252	549,716
Yolo	195,050	84,673
Other counties [1]	2,919,214	4,288,441
Totals	33,786,520	$30,592,965

[1] Production (tons) of all other counties not listed above except Alpine and San Francisco.
[2] Value included with Other counties.

been used in the manufacture of a fertilizer called thermo-phos. The serpentine produced near Almaden, Santa Clara County, is fused with phosphate rock in a plant at Permanente, California, to make a phosphate fertilizer for use on land deficient in phosphorus and magnesium.

Silica. Quartz was mined during 1948 in California from a single property in Kern County; ganister (quartzite) from a property in San Bernardino County; and glass sand from properties in Monterey and Riverside Counties. The annual details on quartz and quartzite are included in the miscellaneous item (table 1), and glass sand is included under *Sand and Gravel.*

Silver. The silver produced in California during 1948 totaled 724,771 fine ounces worth $655,954, as compared with 1,597,442 fine ounces worth $1,445,685 in 1947. The price fixed by the United States Treasury for newly mined silver during 1947-48 was $0.905 a fine ounce, as compared with the 1946 price of $0.808 a fine ounce and the 1940-45 price of $0.7111 a fine ounce.

The following paragraph is quoted from Merrill:[5]

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[5] Merrill, Charles White, Mine production of silver in the United States in 1948: U. S. Bur. Mines, Mineral Market Rept. 1690.

"California.—The sharp drop in output in 1948 placed California seventh among the silver-producing States, behind Nevada, which ranked lower in 1947 ; Nevada took sixth place in 1948, by a substantial margin over California, following an important gain in output. California's output decreased 5.7 percent in 1948. Approximately four-fifths of the total was derived from argentiferous lead and zinc-lead ores, and Anaconda Copper Mining Co., which operated the Darwin group, Coso district, and Shoshone group, Resting Springs district, Inyo County, produced about 60 percent of the State total."

Mine production of silver in California during 1948, by counties.

County	Fine ounces	Value
Alpine	2	$2
Amador	2,252	2,038
Butte	1,990	1,801
Calaveras	640	579
Colusa	1	1
El Dorado and Humboldt [1]	1,404	1,271
Imperial	93	84
Inyo and Fresno [1]	573,329	518,892
Kern	13,509	12,226
Lassen	102	92
Los Angeles	36	33
Madera and Merced [1]	1,894	1,714
Mariposa	2,166	1,960
Modoc	73	66
Mono	788	713
Monterey	6	5
Napa	29	26
Nevada	29,744	26,920
Placer	1,503	1,360
Plumas	66	60
Riverside	101	91
Sacramento	6,491	5,875
San Bernardino and San Joaquin [1]	57,740	52,258
San Diego	3	3
Shasta and Stanislaus [1]	19,951	18,057
Sierra	2,405	2,177
Siskiyou	2,757	2,495
Trinity	1,011	915
Tuolumne	1,113	1,007
Yuba	3,572	3,233
Totals: 1948	724,771	$655,954
1947	1,597,442	$1,445,685

[1] Combined to avoid disclosure of individual output.

Slate. The slate mined in California during 1948 came from properties in El Dorado, Inyo, and Mariposa Counties. The properties in Placer and Tuolumne Counties that shipped slate in 1947 reported no output for 1948.

Soda. Sodium carbonate (soda ash and trona) produced in California during 1948 totaled 288,769 short tons worth $6,623,280, as compared with 293,051 short tons worth $5,862,178 in 1947. The 1947 and 1948 output came from three properties in Inyo County and two properties in San Bernardino County.

The sodium sulfate (salt cake) produced in California during 1948 and 1947 came from two properties in San Bernardino County. The annual details are included under *Miscellaneous* (see table 1).

Stone. During 1948 California produced 11,936,240 short tons of stone (including crushed rock, rubble, rip rap, dolomite, industrial limestone ; and dimension stone such as basalt, granite, limestone, and sandstone) worth $13,155,454, as compared with 12,757,790 short tons worth $13,012,556 in 1947.

Stone production of California during 1948, by counties.

County	Ton	Value
Alameda	1,002,200	$742,900
Amador	21,270	[2]
Butte	224,770	158,895
Contra Costa	499,110	586,904
El Dorado	176,130	490,086
Fresno	416,530	618,459
Humboldt	23,310	[2]
Lake	2,430	[2]
Los Angeles	4,425,270	4,323,469
Monterey	197,150	281,166
Napa	58,130	78,512
Orange	116,130	[2]
Riverside	7,160	12,562
San Bernardino	1,195,970	1,563,225
San Diego	91,570	280,626
San Mateo	780,390	738,085
Santa Barbara	301,890	[2]
Santa Clara	255,040	189,241
Shasta	128,410	[2]
Siskiyou	177,770	57,642
Sonoma	135,690	169,636
Trinity	19,900	20,520
Tuolumne	33,100	223,851
Yolo	45,500	12,250
Other counties [1]	1,601,420	2,607,425
Totals	11,936,240	$13,155,454

[1] Includes Del Norte, Imperial, Inyo, Lassen, Marin, Placer, Sacramento, San Benito, San Francisco, San Joaquin, San Luis Obispo, Santa Cruz, Tulare, and Ventura Counties.

[2] Value included under Other counties.

Stone sold or used by producers in California in 1948.

Kind of stone	Dimension		Crushed	
	Short tons	Value	Short tons	Value
Granite	5,330	$285,214	1,562,010	$1,466,917
Basalt	[1]	[1]	1,312,990	1,379,099
Marble	-----	-----	3,140	56,466
Limestone	1,540	7,210	778,640	1,946,366
Sandstone	6,990	49,015	1,522,120	1,403,923
Miscellaneous stone	700	7,915	6,742,780	6,553,329
Totals	[2] 14,560	[2] $349,354	11,921,680	$12,806,100

[1] Fewer than three producers.

[2] Incomplete total—dimension basalt data not included.

Strontium. During 1948 no shipments of strontium minerals were reported in California. The last production reported was in 1946, from properties in Imperial and San Bernardino Counties.

Sulfur. The sulfur mined and shipped during 1948 in California came from two properties, one in Alpine County and one in Inyo County. The 1947 sulfur output came from two properties in Inyo County.

Talc, Soapstone, and Pyrophyllite. The talc, soapstone, and pyrophyllite mined and shipped in California during 1948 totaled 98,681 short tons worth $1,773,764, and came from properties in El Dorado, Inyo, Los Angeles, Mono, San Bernardino, and San Diego Counties. The 1947 output totaled 91,537 short tons worth $1,595,422. The material produced in 1948 from El Dorado and Los Angeles Counties was soapstone;

the production from San Bernardino County and part of the production from Inyo County was high-grade talc; the production from Mono and San Diego Counties, and part of the production from Inyo County was pyrophyllite.

Talc, soapstone, and pyrophyllite production in California during 1948, by counties.

County	Tons	Value
Inyo	33,546	$471,596
San Bernardino	52,622	1,160,255
El Dorado, Los Angeles, Mono, San Diego	12,513	141,913
Totals	98,681	$1,773,764

Titanium. Titanium concentrate (ilmenite) was produced in California during 1948 from two properties in Sand Canyon near Saugus, Los Angeles County.

Tungsten. High-grade tungsten ore and concentrates mined and shipped in California during 1948 totaled 1,767 short tons (60 percent WO_3 basis). The 1948 output of tungsten ore and concentrates showed a marked increase over that of 1947 when 394 short tons (60 percent WO_3 basis) worth $548,233 was shipped. Eighteen operating properties reported shipments of concentrates and high-grade ore in 1948; these were located in Alpine, Fresno, Inyo, Kern, Madera, Mono, San Bernardino, and Tulare Counties.

Zinc. The recoverable zinc produced in California during 1948 totaled 10,650,000 pounds valued at $1,416,450, as compared with 10,830,000 pounds worth $1,310,430 in 1947. The most important production in 1948 was made at the lead-zinc properties of the Anaconda Copper Mining Company at Darwin and Tecopa, Inyo County. The Coronado Copper and Zinc Company (Afterthought mine at Ingot, Shasta County) was the only large new zinc producer. The San Bernardino County zinc concentrates came from the Carbonate King mine near Nipton.

The average price of prime western-grade slab zinc in 1948, East St. Louis, was 13.3 cents per pound, compared with an average value of 10.5 cents per pound in 1947, and 11.7 cents per pound in 1946, including United States Government premium.

Zinc production in California during 1948, by counties.

County	Pounds	Value
Inyo	9,320,000	$1,239,560
San Bernardino	438,000	58,254
Shasta	892,000	118,636
Totals	10,650,000	$1,416,450

*Value of California mineral production in 1947 and 1948, by counties.**

County	1947	1948	County	1947	1948
Alameda	$8,467,741	$8,771,793	Riverside	$8,381,215	$9,269,937
Alpine	[1]	[1]	Sacramento	14,341,144	16,737,925
Amador	913,189	941,126	San Benito	2,497,039	2,803,469
Butte	1,312,410	1,281,737	San Bernardino	36,699,909	44,640,646
Calaveras	4,199,321	4,662,145	San Diego	1,882,394	2,594,065
Colusa	89,963	20,756	San Francisco	[3]	[3]
Contra Costa	1,405,682	1,255,576	San Joaquin	2,968,420	3,077,835
Del Norte	322,156	186,902	San Luis Obispo	396,393	1,428,990
El Dorado	1,641,020	1,758,799	San Mateo	5,334,024	5,707,031
Fresno	89,626,207	124,450,502	Santa Barbara	40,676,339	60,753,770
Glenn	[2] 388,043	[2] 271,276	Santa Clara	11,978,918	13,317,067
Humboldt	318,364	407,996	Santa Cruz	3,216,500	4,024,125
Imperial	907,843	1,957,508	Shasta	2,271,226	1,680,434
Inyo	6,596,468	10,286,796	Sierra	468,196	384,223
Kern	209,037,916	293,773,122	Siskiyou	1,170,971	1,012,137
Kings	24,750,000	36,337,310	Solano	8,535,751	8,903,771
Lake	107,232	116,787	Sonoma	1,050,051	1,029,437
Lassen	71,828	38,156	Stanislaus	1,113,357	954,234
Los Angeles	203,529,633	278,436,293	Sutter	113,789	130,447
Madera	307,176	446,627	Tehama	[2]	[2]
Marin	461,179	389,245	Trinity	561,555	311,010
Mariposa	333,601	280,739	Tulare	1,527,551	2,057,745
Mendocino	[3] 528,181	[3] 426,130	Tuolumne	901,067	850,342
Merced	742,366	869,757	Ventura	62,807,862	87,543,246
Modoc	116,170	145,490	Yolo	261,428	144,870
Mono	332,893	355,497	Yuba	2,559,132	2,226,195
Monterey	2,979,297	4,196,755			
Napa	359,911	303,385			
Nevada	[1] 3,008,304	[1] 3,659,073	Heavy clay products (not entirely separable by counties) [4]	15,605,828	20,042,303
Orange	68,115,831	103,472,783			
Placer	487,751	512,671			
Plumas	261,100	32,975	State total (rounded)	$859,039,000	$1,174,674,000

* These figures are furnished by the United States Bureau of Mines in cooperation with the California State Division of Mines

[1] Output of Alpine County is included with Nevada County.

[2] Output of Tehama County is included with Glenn County.

[3] Output of San Francisco County is included with Mendocino County.

[4] Figures shown represent value of heavy clay products (other than pottery and refractories) as reported by United States Bureau of the Census, less value of raw clay sold or used for the manufacture of cement and heavy clay products, as follows: 1947—$16,793,000 and $1,187,172, respectively; 1948—$21,600,000 and $1,557,697, respectively.

CONTRIBUTIONS OF THE COUNTIES TO THE MINERAL PRODUCTION OF CALIFORNIA DURING 1948

By Henry H. Symons, Fenelon F. Davis, and Charles V. Averill

The relative position of the 10 leading counties in value of mineral production was the same in 1948 as in 1947. Kern County, the principal producer of petroleum, ranked first. Five other important petroleum-producing counties followed in this order: Los Angeles, Fresno, Orange, Ventura, and Santa Barbara. The production of borates, cement, potash, and soda from the desert areas of San Bernardino County placed that county in seventh position. Kings County, another petroleum producer ranked eighth. Gold from the bucket-line dredges and dry gas from the Rio Vista field combined to put Sacramento County in ninth place. Cement produced by the largest cement mill in the world placed Santa Clara County in tenth position. Inyo County, a basin-range province and principal lead-zinc producer, ranked eleventh. Alameda County, principal producer of salt by solar evaporation, ranked twelfth. Nevada County, principal producer of gold from lode ores, ranked nineteenth.

San Bernardino County produced 24 different minerals in 1948, and was the leading county in diversification of mineral production. Other counties which showed a diversified mineral production in 1948 were Inyo (19 minerals), Kern (17 minerals), Los Angeles (15 minerals), and Fresno (12 minerals).

Mineral production total values exceeding a million dollars were reported from 32 counties in 1948. Million-dollar production values were also reported by one or more counties in 1948 for each of the following 21 mineral products: boron minerals, cement, clay products, diatomite, gold, gypsum, iron ore, lead, lime, natural gas, natural gasoline and allied products, liquefied petroleum gases, petroleum, potassium minerals, salt, sand and gravel, soda minerals, stone, talc, tungsten, and zinc.

*Details of mineral production for each county, 1948 and 1947.**

Alameda County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)		[1] $1,165,000		[1] $1,342,000
Clay, raw — short tons	18,751	18,782	14,404	16,109
Salt (sodium chloride) — do	540,943	3,046,907	663,108	3,091,370
Sand and gravel — do	3,844,057	3,578,314	3,896,600	4,026,285
Stone — do	1,112,500	714,025	1,002,200	742,900
Unapportioned (bromine, lime, and magnesium compounds)		1,109,713		895,129
Total value		$8,467,741		$8,771,793

Alpine County

Minerals produced in Alpine County were: 1947—Tungsten concentrates; 1948—copper, gold, silver, sulfur ore, and tungsten concentrates.

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Amador County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay, raw	short tons	198,264	$380,496	189,884	$625,537
Copper	pounds	1,674,000	351,540	------	------
Gold	troy ounces	4,724	165,340	6,614	231,490
Sand and gravel	short tons	[2]	[2]	34,490	65,476
Silver	troy ounces	11,598	10,496	2,252	2,038
Stone	short tons	[2]	[2]	21,270	[2]
Unapportioned (pumicite and items indicated by footnote 2)		------	5,317	------	16,585
Total value		------	$913,189	------	$941,126

Butte County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Chromite	short tons	308	[2]	------	------
Gold	troy ounces	27,037	$946,295	26,137	$914,795
Sand and gravel	short tons	55,643	57,123	148,990	192,798
Silver	troy ounces	2,201	1,992	1,990	1,801
Stone	short tons	[2]	[2]	224,770	158,895
Unapportioned (natural gas, crude platinum metals, and items indicated by footnote 2)		------	307,000	------	16,448
Total value		------	$1,312,410	------	$1,284,737

Calaveras County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Copper	pounds	1,242,000	$260,820	------	------
Gold	troy ounces	5,171	180,985	1,196	41,860
Lead	short tons	90	25,920	1	358
Sand and gravel	do	[2]	[2]	113,871	204,507
Silver	troy ounces	97,076	87,854	640	579
Stone	short tons	[2]	[2]	------	------
Zinc	do	2,350	568,700	------	------
Unapportioned (cement, raw clay, pumice, and items indicated by footnote 2)		------	3,075,042	------	4,414,841
Total value		------	$4,199,321	------	$4,662,145

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Colusa County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Gold	troy ounces	6	$210	2	$70
Sand and gravel	short tons	225,729	89,750	65,711	20,685
Silver	troy ounces	3	3	1	1
Total value		------------	$89,963	------------	$20,756

Contra Costa County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)		------------	[3]	------------	[2]
Peat	short tons	------------	------------	[2]	[2]
Sand and gravel	do	378,734	$248,403	372,013	$252,229
Stone	do	472,020	509,645	499,110	586,904
Unapportioned (raw clay, natural gas, pumice, and item indicated by footnote 2)		------------	647,733	------------	416,443
Total value		------------	$1,405,682	------------	$1,255,576

Del Norte County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Chromite	short tons	640	[2]	274	[2]
Mercury	flasks	------------	------------	5	$382
Sand and gravel	short tons	55,017	[2]	[2]	[2]
Unapportioned (stone and items indicated by footnote 2)		------------	$322,156	------------	186,520
Total value		------------	$322,156	------------	$186,902

El Dorado County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Copper	pounds	112,000	$23,520	72,000	$15,624
Gold	troy ounces	2,994	104,790	2,592	90,720
Lead	short tons	2	576	------------	------------
Silver	troy ounces	2,039	1,845	1,391	1,259
Stone	short tons	211,780	483,991	176,130	490,086
Zinc	do	6	1,452	------------	------------
Unapportioned (lime, sand and gravel, slate, and soapstone)		------------	1,024,846	------------	1,161,110
Total value		------------	$1,641,020	------------	$1,758,799

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Fresno County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)		------------	[3]	------------	[3]
Gold	troy ounces	235	$8,225	[2]	[2]
Gypsum, crude	short tons	[2]	[2]	15,443	$23,271
Mercury	flasks	[2]	[2]	------------	------------
Natural gas	M cu. ft.	65,636,000	6,943,000	69,644,000	7,224,000
Natural gasoline and allied products:					
Natural gasoline [4]	gallons	75,488,000	3,990,000	26,623,000	2,199,000
Liquefied petroleum gases [4]	do	41,170,000	1,642,000	22,262,000	1,400,000
Petroleum	barrels	44,137,000	75,560,000	45,841,000	111,920,000
Sand and gravel	short tons	1,031,322	1,141,346	932,804	1,022,024
Silver	troy ounces	37	33	[2]	[2]
Stone	short tons	164,910	292,835	416,530	618,459
Tungsten concentrates (60% WO_3 basis)	short tons	[2]	[2]	11	15,858
Unapportioned (raw clay and items indicated by footnote 2)		------------	48,768	------------	27,890
Total value		------------	$89,626,207	------------	$124,450,502

Glenn County

Production in Glenn County in 1947-48 consisted of natural gas and sand and gravel.

Humboldt County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)		------------	[3]	------------	[3]
Gold	troy ounces	139	$4,865	[2]	[2]
Sand and gravel	short tons	261,063	221,278	359,243	$293,016
Silver	troy ounces	22	20	[2]	[2]
Stone	short tons	60,120	[2]	23,310	[2]
Unapportioned (raw clay, natural gas, and items indicated by footnote 2)		------------	92,201	------------	114,980
Total value		------------	$318,364	------------	$407,996

Imperial County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Gold	troy ounces	------------	------------	171	$5,985
Mica (scrap)	short tons	[2]	[2]	------------	------------
Sand and gravel	do	232,704	[2]	488,277	[2]
Silver	troy ounces	------------	------------	93	84
Stone	short tons	------------	------------	[2]	[2]
Unapportioned (crude gypsum and items indicated by footnote 2)		------------	$907,843	------------	1,951,439
Total value		------------	$907,843	------------	$1,957,508

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Inyo County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Antimony ore	short tons	-----------	-----------	5	$1,467
Copper	pounds	232,000	$48,720	598,000	129,766
Gold	troy ounces	1,974	69,090	1,794	62,790
Lead	short tons	8,990	2,589,120	8,620	3,085,960
Sand and gravel	do	[2]	[2]	105,176	111,937
Silver	troy ounces	1,235,998	1,118,578	573,283	518,850
Slate		-----------	-----------	-----------	[2]
Stone	short tons	69,320	118,471	[2]	[2]
Sulfur ore	long tons	698	9,074	[2]	[2]
Talc and pyrophyllite	short tons	30,444	482,007	33,546	471,596
Zinc	do	702	169,884	4,660	1,239,560
Unapportioned (boron minerals, raw clay, diatomite, fuller's earth, molybderum, pumice and pumicite, sodium salts, tungsten concentrates, and items indicated by footnote 2)		-----------	1,991,524	-----------	4,664,870
Total value		-----------	$6,596,468	-----------	$10,286,796

Kern County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)		-----------	[3]	-----------	[3]
Clay, raw	short tons	213,475	$746,372	215,953	$768,280
Feldspar, crude	long tons	-----------	-----------	[2]	[2]
Gold	troy ounces	6,228	217,980	6,176	216,160
Gypsum, crude	short tons	[5] 352,977	[5] 558,269	271,908	414,233
Natural gas	M cu. ft.	88,753,000	8,566,000	84,803,000	8,414,000
Natural gasoline and allied products:					
Natural gasoline	gallons	134,520,000	6,839,000	143,654,000	11,865,000
Liquefied petroleum gases	do	90,458,000	3,452,000	107,801,000	6,781,000
Petroleum	barrels	106,058,000	176,761,000	105,426,000	253,636,000
Sand and gravel	short tons	608,674	671,917	581,495	663,945
Silver	troy ounces	7,686	6,956	13,509	12,226
Stone	short tons	[2]	[2]	-----------	-----------
Unapportioned (boron minerals, cement, pumice and pumicite, quartz, salt, tungsten concentrates, and items indicated by footnote 2)		-----------	11,218,422	-----------	11,002,278
Total value		-----------	$209,037,916	-----------	$293,773,122

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Kings County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Gypsum, crude short tons	[5]	[5]	[2]	[2]
Natural gas M cu. ft.	41,113,000	$4,404,000	40,310,000	$4,545,000
Natural gasoline and allied products:				
Natural gasoline [4] gallons	63,534,000	3,512,000	116,075,000	9,587,000
Liquefied petroleum gases [4] do	36,525,000	1,317,000	66,480,000	4,182,000
Petroleum barrels	7,504,000	15,517,000	6,551,000	17,965,000
Sand and gravel short tons			[2]	[2]
Unapportioned (items indicated by footnote 2)				58,310
Total value		$24,750,000		$36,337,310

Lake County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Mercury flasks	364	[2]	[2]	[2]
Sand and gravel short tons	70,284	[2]	125,008	[2]
Stone do	[2]	[2]	2,430	[2]
Unapportioned (items indicated by footnote 2)		$107,232		$116,787
Total value		$107,232		$116,787

Lassen County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Gold troy ounces	1	$35	121	$4,235
Silver do	6	5	102	92
Stone short tons	42,980	[2]	[2]	[2]
Unapportioned (sand and gravel and items indicated by footnote 2)		71,788		33,829
Total value		$71,828		$38,156

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Los Angeles County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)		----	[1] $10,936,000	----	[1] $14,791,000
Clay, raw	short tons	477,011	436,146	491,167	368,784
Gold	troy ounces	48	1,680	215	7,525
Lime	short tons	[2]	[2]	----	----
Natural gas	M cu. ft.	98,435,000	8,586,000	102,783,000	11,588,000
Natural gasoline and allied products:					
Natural gasoline	gallons	299,343,000	16,098,000	313,871,000	25,923,000
Liquefied petroleum gases	do	16,036,000	491,000	19,982,000	1,257,000
Petroleum	barrels	91,897,000	164,496,000	91,096,000	223,002,000
Quartz	short tons	[2]	[2]	----	----
Sand and gravel	do	11,088,519	6,866,923	11,909,517	8,085,435
Silver	troy ounces	6	5	36	33
Stone	short tons	4,284,150	3,167,650	4,425,270	4,323,469
Titanium concentrates (ilmenite)	do	----	----	[2]	[2]
Unapportioned (cement, diatomite, iodine, soapstone, and items indicated by footnote 2)		----	3,386,229	----	3,881,047
Total value		----	$203,529,633	----	$278,436,293

Madera County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Copper	pounds	----	----	10,000	$2,170
Feldspar	long tons	[2]	[2]	----	----
Gold	troy ounces	197	$6,895	[2]	[2]
Pumice and pumicite	short tons	21,730	153,473	8,311	82,719
Sand and gravel	do	----	----	26,399	19,040
Silver	troy ounces	57	52	[2]	[2]
Stone	short tons	[2]	[2]	----	----
Tungsten concentrates (60% WO_3 basis)	do	[2]	[2]	58	[2]
Unapportioned (natural gas and items indicated by footnote 2)		----	146,756	----	342,698
Total value		----	$307,176	----	$446,627

Marin County

Production in Marin County in 1947 and 1948 consisted of raw clay, sand and gravel, and stone.

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Mariposa County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Copper pounds	4,000	$840		
Gold troy ounces	6,363	222,705	7,525	$263,375
Platinum metals (crude) do			[2]	[2]
Quartz short tons	[2]	[2]		
Sand and gravel do	[2]	[2]	17,127	13,331
Silver troy ounces	1,933	1,749	2,166	1,960
Slate				[2]
Stone short tons	[2]	[2]		
Unapportioned (barite and items indicated by footnote 2)		108,307		2,073
Total value		$333,601		$280,739

Mendocino County

Production in Mendocino County in 1947 and 1948 consisted of sand and gravel.

Merced County

Production in Merced County in 1947 and 1948 consisted of gold, crude platinum metals, sand and gravel, and silver.

Modoc County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Gold troy ounces			141	$4,935
Pumice short tons	[2]	[2]	14,165	79,095
Sand and gravel do	198,513	[2]	114,018	61,394
Silver troy ounces			73	66
Stone short tons	79,180	[2]		
Unapportioned (items indicated by footnote 2)		$116,170		
Total value		$116,170		$145,490

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Mono County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Copper	pounds	18,000	$3,780		
Gold	troy ounces	41	1,435	63	$2,205
Lead	short tons	17	4,896	2	716
Pumice	do	4,738	220,088	8,582	257,335
Silver	troy ounces	7,323	6,627	788	713
Stone	short tons	[2]	[2]		
Tungsten concentrates (60% WO_3 basis)	do	[2]	[2]		
Unapportioned (pyrophyllite, sand and gravel, and items indicated by footnote 2)			96,067		94,528
Total value			$332,893		$355,497

Monterey County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Gold	troy ounces			24	$840
Sand and gravel	short tons	646,973	$1,022,058	808,160	1,525,600
Silver	troy ounces			6	5
Stone	short tons	147,730	232,980	197,150	281,166
Unapportioned (lime, magnesium compounds, petroleum, salt, and ground sand and sandstone)			1,724,259		2,389,144
Total value			$2,979,297		$4,196,755

Napa County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Gold	troy ounces			2	$70
Perlite, crude	short tons			[2]	[2]
Sand and gravel	do	[2]	[2]	37,670	32,600
Silver	troy ounces			29	26
Stone	short tons	161,440	$202,386	58,130	78,512
Unapportioned (mercury, pumice and pumicite, and items indicated by footnote 2)			157,525		192,177
Total value			$359,911		$303,385

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Nevada County

Minerals produced in Nevada County were: 1947—gold, silver, and stone; 1948—gold, sand and gravel, and silver.

Orange County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)	-----	[3]	-----	[3]
Clay, raw — short tons	20,437	$72,520	19.292	$74,984
Natural gas — M cu. ft.	30,238,000	2,535,000	30,844,000	3,338,000
Natural gasoline and allied products:				
Natural gasoline — gallons	114.894,000	5,974,000	115,378,000	9,529,000
Liquefied petroleum gases — do	4,472,000	145,000	9,785,000	615,000
Petroleum — barrels	34,149,000	58,407,000	38,217,000	91,929,000
Sand and gravel — short tons	961,207	812,831	908,737	813,411
Stone — do	[2]	[2]	116,130	[2]
Unapportioned (peat, salt, and items indicated by footnote 2)	-----	169,480	-----	173,388
Total value	-----	$68,115,831	-----	$106,472,783

Placer County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)	-----	[3]	-----	[3]
Gold — troy ounces	5,358	$187,530	1,330	$46,550
Silver — do	807	730	1,503	1,360
Slate	-----	[2]	-----	-----
Stone — short tons	100,410	81,976	[2]	[2]
Unapportioned (asbestos, raw clay, sand and gravel, and items indicated by footnote 2)	-----	217,515	-----	464,761
Total value	-----	$487,751	-----	$512,671

Plumas County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Barite — short tons	[2]	[2]	-----	-----
Copper — pounds	28,000	$5,880	-----	-----
Gold — troy ounces	546	19,110	699	$24,465
Sand and gravel — short tons	[2]	[2]	18,300	8,450
Silver — troy ounces	570	516	66	60
Stone — short tons	201,480	[2]	-----	-----
Unapportioned (items indicated by footnote 2)	-----	235,594	-----	-----
Total value	-----	$261,100	-----	$32,975

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Riverside County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)			[3]		[3]
Clay, raw	short tons	283,177	[2]	339,996	$562,241
Gold	troy ounces	30	$1,050	4	140
Iron ore	long tons	27,029	[2]	66,617	[2]
Lead	short tons			1	358
Sand and gravel	do	472,839	517,871	802,621	482,844
Silver	troy ounces	15	14	101	91
Stone	short tons	138,250	156,700	7,160	12,562
Unapportioned (cement, crude gypsum, and items indicated by footnote 2)			7,705,580		8,211,698
Total value			$8,381,215		$9,269,937

Sacramento County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)			[1] $340,000		[1] $368,000
Clay, raw	short tons	30,619	[2]	23,495	[2]
Gold	troy ounces	113,560	3,974,600	118,152	4,135,320
Natural gas	M cu. ft.	74,964,000	8,595,000	81,791,000	10,874,000
Platinum metals (crude)	troy ounces	[2]	[2]	71	[2]
Sand and gravel	short tons	1,564,464	1,334,108	1,453,173	1,353,347
Silver	troy ounces	6,203	5,614	6,491	5,875
Stone	short tons	269,400	375,438	[2]	[2]
Unapportioned (items indicated by footnote 2)			56,384		369,383
Total value			$14,341,144		$16,737,925

San Benito County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Mercury	flasks	9,228	$772,753	[2]	[2]
Petroleum	barrels			[2]	[2]
Stone	short tons	1,013,980	[2]	[2]	[2]
Unapportioned (cement, raw clay, sand and gravel, and items indicated by footnote 2)			1,724,316		$2,803,469
Total value			$2,497,069		$2,803,469

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

San Bernardino County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Calcium-magnesium chloride	short tons	7,968	$111,950	10,009	$167,610
Clay, raw	do	63,491	232,206	165,303	386,355
Coke	do	332,244	[6]	296,749	[6]
Copper	pounds	92,000	19,320	118,000	25,606
Feldspar, crude	long tons	----------	----------	[2]	[2]
Gold	troy ounces	4,409	154,315	1,518	53,130
Iron ore	long tons	346,545	[2]	279,246	[2]
Iron, pig	short tons	453,376	[6]	375,113	[6]
Lead	do	158	45,504	419	150,002
Lime	do	31,457	328,329	27,393	405,411
Pumice	do	----------	----------	[2]	[2]
Salt (sodium chloride)	do	150,293	386,742	[2]	[2]
Sand and gravel	do	1,151,258	1,124,251	1,671,019	1,560,323
Silver	troy ounces	103,877	94,009	57,538	52,075
Stone	short tons	558,580	827,992	1,195,970	1,563,225
Talc	do	46,535	997,416	52,622	1,160,255
Tungsten concentrates (60% WO_3 basis)	do	[2]	[2]	263	[2]
Zinc	short tons	650	157,300	219	58,254
Unapportioned (boron minerals, bromine, cement, lithium minerals, petroleum, potassium salts, quartz, sodium salts, and items indicated by footnote 2)		----------	32,220,545	----------	39,058,400
Total value		----------	$36,699,909	----------	$44,640,646

San Diego County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)		----------	[3]	----------	[3]
Clay, raw	short tons	14,533	$15,005	35,222	$60,922
Gold	troy ounces	13	455	8	280
Sand and gravel	short tons	1,195,011	1,324,830	1,395,701	1,829,989
Silver	troy ounces	6	5	3	3
Stone	short tons	79,410	196,037	91,570	280,626
Unapportioned (magnesium compounds, pebbles for grinding, pyrophyllite, and salt)		----------	346,062	----------	422,245
Total value		----------	$1,882,394	----------	$2,594,065

San Francisco County

Production in San Francisco County was as follows: 1947—heavy clay products, gold, and stone; 1948—heavy clay products and stone.

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

San Joaquin County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)	------------	[1] $291,000	------------	[1] $274,000
Clay, raw ---------- short tons	[2]	[2]	18,184	14,259
Natural gas ---------- M cu. ft.	9,926,000	1,297,000	8,277,000	1,313,000
Platinum metals (crude) ---------- troy ounces	------------	------------	[2]	[2]
Sand and gravel ---------- short tons	1,598,607	1,330,544	1,679,808	1,617,023
Unapportioned (gold, silver, stone, and items indicated by footnote 2)	------------	340,876	------------	133,553
Total value	------------	$2,968,420	------------	$3,077,835

San Luis Obispo County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)	------------	[3]	------------	[3]
Mercury ---------- flasks	449	$37,599	[2]	[2]
Petroleum ---------- barrels	[2]	[2]	460,000	$1,208,000
Pumicite ---------- short tons	------------	------------	[2]	[2]
Sand and gravel ---------- do	[2]	[2]	165,064	205,053
Unapportioned (raw clay, stone, and items indicated by footnote 2)	------------	358,794	------------	15,937
Total value	------------	$396,393	------------	$1,428,990

San Mateo County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Clay, raw ---------- short tons	------------	------------	[2]	[2]
Stone ---------- do	1,078,700	$1,184,602	$780,390	738,085
Unapportioned (cement, magnesium compounds, sand and gravel, and item indicated by footnote 2)	------------	4,149,422	------------	4,968,946
Total value	------------	$5,334,024	------------	$5,707,031

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Santa Barbara County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)		[3]		[3]
Natural gas M cu. ft.	18,586,000	$1,355,000	20,329,000	$1,925,000
Natural gasoline and allied products:				
Natural gasoline gallons	36,059,000	1,881,000	24,987,000	2,064,000
Liquefied petroleum gases do	1,523,000	51,000	8,419,000	530,000
Petroleum barrels	22,465,000	33,297,000	23,756,000	51,992,000
Sand and gravel short tons	198,897	[2]	185,629	[2]
Stone do	379,890	[2]	301,890	[2]
Unapportioned (raw clay, diatomite, and items indicated by footnote 2)		4,092,339		4,242,770
Total value		$40,676,339		$60,753,770

Santa Clara County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Clay products, heavy clay (other than pottery and refractories)		[1] $1,201,000		[1] $1,271,000
Clay, raw short tons	158,206	[2]	177,780	[2]
Ferro-alloys do	5,278	[6]	[6]	[6]
Mercury flasks	586	49,072	[2]	[2]
Sand and gravel short tons	352,266	[2]	457,451	[2]
Stone do	400,080	462,732	255,040	189,241
Unapportioned (cement, magnesite, petroleum, and items indicated by footnote 2)		11,467,114		13,127,826
Total value		$11,978,918		$13,317,067

Santa Cruz County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Asphalt short tons	[2]	[2]		
Lime do	[2]	[2]		
Peat do	[2]	[2]		
Stone do	27,280	$134,127	[2]	[2]
Unapportioned (cement, raw clay, sand and gravel, and items indicated by footnote 2)		3,082,373		$4,024,125
Total value		$3,216,500		$4,024,125

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Shasta County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Copper	pounds	1,396,000	$293,160	156,000	$33,852
Gold	troy ounces	[2]	[2]	11,538	403,830
Lead	short tons	817	235,296	53	18,974
Platinum metals (crude)	troy ounces			[2]	[2]
Sand and gravel	short tons	258,960	224,273	490,722	440,953
Silver	troy ounces	[2]	[2]	18,935	17,137
Stone	short tons	[2]	[2]	128,410	[2]
Zinc	do	1,707	413,094	446	118,636
Unapportioned (asbestos, pyrites, and items indicated by footnote 2)			1,105,403		647,052
Total value			$2,271,226		$1,680,434

Sierra County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Copper	pounds			2,000	$434
Gold	troy ounces	13,263	$464,205	10,430	365,050
Lead	short tons	6	1,728	14	5,012
Sand and gravel	do			33,000	11,550
Silver	troy ounces	2,501	2,263	2,405	2,177
Total value			$468,196		$384,223

Siskiyou County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Gold	troy ounces	[2]	[2]	21,226	$742,910
Platinum metals (crude)	do			[2]	[2]
Pumice	short tons	19,965	$143,963	35,577	173,136
Silver	troy ounces	[2]	[2]	2,757	2,495
Stone	short tons	188,970	149,679	177,770	57,642
Unapportioned (diatomite, sand and gravel, and items indicated by footnote 2)			877,329		35,954
Total value			$1,170,971		$1,012,137

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Solano County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Natural gas	M cu. ft.	67,278,000	$8,388,000	66,212,000	$8,746,000
Unapportioned (sand and gravel, and stone)			147,751		157,771
Total value			$8,535,751		$8,903,771

Sonoma County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Mercury	flasks	4,247	$355,644	[2]	[2]
Natural gas	M cu. ft.			[2]	[2]
Petroleum	barrels			[2]	[2]
Pumice	short tons	[2]	[2]		
Sand and gravel	do	584,044	515,340	[2]	[2]
Stone	do	141,370	[2]	135,690	$169,636
Unapportioned (items indicated by footnote 2)			179,067		859,801
Total value			$1,050,051		$1,029,437

Stanislaus County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Pumicite	short tons			2,066	$3,840
Sand and gravel	do	392,090	$439,054	364,719	454,660
Stone	do	[2]	[2]		
Unapportioned (raw clay, gold, natural gas, silver, and item indicated by footnote 2)			674,303		495,734
Total value			$1,113,357		$954,234

Sutter County

Production in Sutter County in 1947 and 1948 consisted of raw clay, natural gas, and sand and gravel.

Tehama County

Minerals produced in Tehama County were: 1947—sand and gravel, and stone; 1948—sand and gravel.

*Details of mineral production for each county, 1948 and 1947 *—Continued.*

Trinity County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Copper	pounds	[2]	[2]		
Gold	troy ounces	13,905	$486,675	7,930	$277,550
Sand and gravel	short tons	[2]	[2]	8,845	12,025
Silver	troy ounces	[2]	[2]	1,011	915
Stone	short tons	[2]	[2]	19,900	20,520
Unapportioned (items indicated by footnote 2)			74,880		
Total value			$561,555		$311,010

Tulare County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Clay, raw	short tons			[2]	[2]
Natural gas	M cu. ft.	[2]	[2]	10,672,000	$1,465,000
Sand and gravel	short tons	[2]	[2]	236,646	290,205
Stone	do	92,040	$132,457	[2]	[2]
Tungsten concentrates (60% WO_3 basis)	do	[2]	[2]	138	197,025
Unapportioned (items indicated by footnote 2)			1,395,094		105,515
Total value			$1,527,551		$2,057,745

Tuolumne County

Product		1947		1948	
		Quantity	Value	Quantity	Value
Copper	pounds	12,000	$2,520		
Gold	troy ounces	4,232	148,120	1,314	$45,990
Silver	do	2,015	1,824	1,113	1,007
Soapstone	short tons	[2]	[2]		
Stone	do	43,330	252,189	33,100	223,851
Unapportioned (lime, sand and gravel, and item indicated by footnote 2)			496,414		579,494
Total value			$901,067		$850,342

Details of mineral production for each county, 1948 and 1947 [*]—Continued.

Ventura County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Natural gas M cu. ft.	47,457,000	$4,517,000	46,023,000	$4,359,000
Natural gasoline and allied products:				
Natural gasoline gallons	109,635,000	8,008,000	101,837,000	8,411,000
Liquefied petroleum gases do	40,451,000	803,000	34,915,000	2,196,000
Petroleum barrels	26,860,000	48,861,000	28,617,000	71,790,000
Sand and gravel short tons	676,173	[2]	664,252	549,716
Unapportioned (raw clay, stone, and item indicated by footnote 2)		618,862		237,530
Total value		$62,807,862		$87,543,246

Yolo County

Product	1947		1948	
	Quantity	Value	Quantity	Value
Sand and gravel short tons	167,650	$70,276	195,050	$84,673
Stone do	[2]	[2]	45,500	12,250
Unapportioned (mercury, natural gas, and item indicated by footnote 2)		191,152		47,947
Total value		$261,428		$144,870

Yuba County

Production in Yuba County in 1947 and 1948 consisted of gold, crude platinum metals, sand and gravel, and silver.

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[*] These figures are furnished by the United States Bureau of Mines in cooperation with the California State Division of Mines.

[1] According to United States Bureau of the Census. Value not included in county total.

[2] Value included with Unapportioned.

[3] United States Bureau of the Census not at liberty to publish figure. Value not included in county total.

[4] Natural gasoline and liquefied petroleum gases processed in Kettleman Hills oil field came from gas produced in both Kings and Fresno Counties. Such production is here assigned entirely to Kings County, because figures by county are not available.

[5] A small quantity of crude gypsum produced in Kings County is included with Kern County.

[6] Bureau of Mines not at liberty to publish figure. Value not included in county and state totals.

PART II

MINERAL FUELS

CONTENTS

COAL

By Lewis T. Braun

Coal was first mined in California in 1855, and the peak annual output of 236,950 tons was reached in 1880. Since 1910 production has been much lower, principally because of competition from petroleum. For the past few years the annual production of coal in California has not exceeded a few hundred tons. Compared to the total United States production, which in 1948 was 651,052,000 tons,[1] California's yield is of little national significance. The California coal industry, however, is of considerable interest historically, and recent developments in the extraction of waxes and pigments from high-volatile coals and lignites may lead to at least a partial revival of the industry in the state. The current interest in raw materials for synthetic fuels may also justify a re-examination of California coal deposits.

Geological Occurrence. Coal is a solid carbonaceous substance composed of vegetal detritus, which has been partly decomposed by various biochemical and dynamochemical processes. It is generally believed that formation of coal requires that the vegetal material must fall into and be covered by fresh water shortly after it dies. The water prevents the rapid decay and decomposition of the vegetation and allows it to accumulate. The transformation from vegetation to rock is a slow process which requires geological ages to complete. In general, the older coal beds contain higher-rank coals than the younger beds.

Most of the commercial coal deposits in the United States were deposited during the Carboniferous or Cretaceous periods, and contain relatively high-ranking coals. The coal deposits of California were deposited later in geologic time (in the Paleocene, Eocene, or Miocene epochs of the Tertiary period), and contain the lignite and sub-bituminous varieties which have a relatively low rank. At each California locality the coal seams are interbedded with sandstone, shale, or clay. These beds were deposited in lagoons, swamps, or shallow lakes marginal to the sea. In the Coast Ranges, Transverse Ranges, and Peninsular Ranges, most of the coal-bearing formations dip steeply. Along the east side of the San Joaquin Valley, in the foothills of the Sierra Nevada, they dip gently or are horizontal.

Detailed geological mapping and examination of the near-shore continental facies of Paleocene to Miocene formations in California may extend coal reserves of the state.

Early Production History. The first recorded discovery of coal in California was in 1847, near the town of San Luis Obispo.[2] In 1850 coal was found in San Diego County and in 1852 in Contra Costa County. The Contra Costa County mines on the northeast slopes of Mt. Diablo, which were first worked in a small way in 1855,[3] were destined to become the largest producers of coal in California, and by 1859 they were supplying a fair proportion of the domestic coal used in San Francisco. In 1870, more than 1,000 men were employed at the Mt. Diablo mines, and the towns of Nortonville and Somersville existed primarily as mining towns. The production of the Mt. Diablo properties fell off rapidly about

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[1] 1948: Year of coal progress: Coal Age, vol. 54, no. 2, p. 83, Feb. 1949.

[2] Boalich, E. S., Bibliography of coal in California: California Min. Bur. Rept. 18, p. 153, 1922.

[3] Bancroft, H. H., History of California, vol. 7, 1860-90, p. 661, The History Company, 1890.

the turn of the century, and there has been virtually no production since 1902.

About 1857, deposits of coal were discovered at Corral Hollow near Tesla in Alameda County.[4] For a few years, beginning in 1897, these deposits were intensively developed. In 1904 the Tesla mines were the largest producers in the state, but the same factors that caused the economic collapse of the Mt. Diablo coal fields also forced the Tesla mines to shut down a few years later.

In 1888 the Southern Pacific Company built a branch line into a lignite locality in Fresno County. The locality was known as ''Coaling Station,'' and supplied a small amount of lignite for a few years. There has been no production from this area since 1896. The original town of ''Coaling Station'' is now known as Coalinga.

Lignite beds in the Ione region in Amador County were mined for local use early in the sixties.[5] Commercial development of the fields started in 1888, and during the period 1888-1903 moderate amounts of coal were marketed in the Sacramento and San Joaquin Valley trade. Since 1903 production from this region has been sporadic. Coal beds near Alberhill in Riverside County were mined in a small way during the period 1894-1902.

The declining market for California coal caused most of the producers to erect briquetting plants in a futile attempt to compete with petroleum.[6] The history of these plants is one of failure and disaster; most of them have been destroyed by fire.

A deposit of sub-bituminous coal at Stone Canyon, Monterey County,[7] was opened in 1907. This deposit, which was discovered in 1870, contains some of the highest-rank coal in the state. In 1909 a large quantity of coal was mined at Stone Canyon, but as the San Francisco market was flooded with low-priced Australian coal, the mine did not show a profit. Late in 1909, heavy floods and a cloudburst damaged the property. In October the company passed into the hands of a receiver. Since then a few attempts have been made to work this property, but none have been successful.

Deposits of sub-bituminous coal have long been known in the Eel River district, Mendocino County, but their remoteness hindered their development. These deposits were operated in the years 1923-26, but only a relatively small amount of coal was marketed.

Recent Developments. In the last few years an industry has developed in the Ione area, which makes the United States self-sufficient in a new raw material.[8] This is the extraction of montan wax from the Ione lignite beds. Montan wax, which was formerly imported from Germany, is similar to carnauba wax and is used in carbon paper, phonograph records, polishes, and rubber. The American Lignite Products Company, the western division of the De Angelis Coal Company of Carbondale, Pennsylvania, operates the Ione plant, which is the only

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[4] Goodyear, W. A., Notes descriptive of the condition of the Corral Hollow coal mines, California Geol. Survey, Geology, vol. 2, app., p. 38, 1882.

[5] Goodyear, W. A., Coal mines of the western coast of the United States, p. 79, A. L. Bancroft & Co., 1877.

[6] Parker, Edward W., Coal, California: Mineral Resources U. S., 1903, pp. 442-443, 1904. . . . 1904, pp. 458-459, 1905. . . . 1905, pp. 554-555, 1906. . . . 1906, pp. 653-654, 1907.

[7] Parker, Edward W., Coal, California: Mineral Resources U. S., 1907, pt. 2, pp. 99-100, 1908. . . . 1908, pt. 2, pp. 99-100, 1909. . . . 1909, pt. 2, pp. 102-103, 1911.

[8] Sawyer, F. G., Montan by the mountain: Ind. and Eng. Chemistry, vol. 41, no. 4, pp. 14A-16A, April 1949.

one of its kind in the United States. Similar lignite extraction plants operated in Germany at one time.

The petroleum solvents which are used to extract the wax are recovered through a counter-current extraction system and steam distillation which removes the solvents from the wax. Montan wax is the principal product, but two other materials are also recovered: sap brown, a dye which is used in the manufacture of paper; and Van Dyke brown, a pigment used in the paint industry. The sediment left after the extraction process is completed is compounded with certain chemicals, and marketed as a soil conditioner and fertilizer.

A very small coal production has been reported from Trinity and Mendocino Counties for the past few years. This has been used locally for miscellaneous purposes.

Mt. Diablo District.[9] The coal measures in the Mt. Diablo district are in the Domengine formation (middle Eocene), and crop out around the northern slopes of Mt. Diablo. The beds dip from 12° to 35° N. In general, the surface coal is deeply weathered, and the quality of the coal improves down to 200 feet below the surface. The two principal coal seams in this area are the Clark vein and the Black Diamond vein. Coal from both these veins has been classed by the U. S. Bureau of Mines as sub-bituminous.

The Clark vein ranges from 1½ to 4½ feet in thickness, and is generally free of any interstratified slate or other undesirable material. The Black Diamond vein, which occurs about 375 feet stratigraphically below the Clark vein, ranges from 6 to 18 feet in thickness, but contains much interstratified clay, slate, and "bone."[10] At some places in the district small coal seams that occur stratigraphically between the Clark and Black Diamond seams have been mined.

Corral Hollow District. The coal beds at Corral Hollow, like those at Mt. Diablo, are in middle Eocene sediments. There are several coal horizons at this locality, but only two appear thick enough to be worked.[11] These coal beds dip steeply, up to 70 degrees. Numerous faults and crushed zones hamper mining. The U. S. Bureau of Mines has classified this coal as sub-bituminous.

Ione District. The Ione (middle Eocene) formation is a series of clay, shale, and sandstone beds exposed in isolated patches along the eastern edge of the Central Valley of California, from Cherokee in Butte County south to Daulton in Madera County. At some localities, notably near the town of Ione in Amador County, the formation contains large amounts of brown lignite. This lignite is found in lens-shaped bodies that were deposited in lagoons along the eastern margin of the Ione sea. These beds are comparatively undisturbed, and seldom are more than 125 feet below the surface. Lignite beds up to 20 feet thick have been reported. Vestiges of bark and woody texture are common in this lignite, and lumps of ionite, a bronish-yellow, earthy hydrocarbon, are occasionally found.

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[9] Goodyear, W. A., The coal mines of the western coast of the United States, pp. 6-69, A. L. Bancroft and Company, 1877.

Goodyear, W. A., Detailed description of the Monte Diablo coal field: California Geol. Survey, Geology, vol. 11, app. pp. 3-27, 1882.

[10] "Bone" is a miner's term for impure, slaty coal.

[11] Smith, George O., The coal fields of the Pacific Coast: U. S. Geol. Survey 22d Ann. Rept., pt. 3, p. 500, 1902.

Stone Canyon District. In Stone Canyon, southern Monterey County, a bed of high-volatile bituminous coal[12] is found near the base of a series of lower Miocene sandstones and shales. This coal bed averages between 14 and 16 feet in thickness, is steeply dipping, and can be traced for 2¼ miles along the strike.[13] Because of its peculiar chemical composition this coal has been called a canneloid; however, on the basis of a microscopic examination, White and Thiessen[14] have termed it a "much metamorphosed woody coal."

Eel River District. Near Covelo and Dos Rios in Mendocino County, isolated patches of the middle Miocene Temblor formation are downfaulted into the underlying Franciscan (Jurassic) sandstones.[15] At this locality the Temblor contains one or more beds of a good grade of subbituminous coal. Where Salt Creek joins the Middle Fork of the Eel River, a prominent ledge of coal crosses the channel of the latter. Goodyear,[16] writing in 1877, described this coal as the best he had seen in California, and reported that the bed was 14 to 15 feet thick with a single thin streak of shale in the center.

Alberhill Area and Santa Ana Mountains. Many coal seams have been encountered in clay quarries of the Alberhill and Santa Ana Mountain areas of Riverside and Orange Counties. The seams, which occur in the Martinez (Paleocene) formation, are lignitic and relatively thin. The coal was mined in the past, but only sporadically, and never on a scale comparable with the operations at Mt. Diablo or Tesla.

COKE

By James W. Vernon

Metallurgical-grade coke has been produced in California only since 1943. This output is obtained at the Kaiser Company's Fontana steel plant which uses coal from Utah and Arkansas as raw material. There is no record of previous commercial coke production in California. California produces but small amounts of non-coking coal and depends on other western states for coking coal to support its expanding iron- and steel-smelting industry.

Coke is the "porous residue that remains after certain bituminous coals have been subjected to heat out of contact with air."[1] Its quality depends largely upon the nature of the coal. Bituminous coals which are low in ash, sulfur, and phosphorus, yield the best coke. A good coke contains approximately 85 to 90 percent fixed carbon, 0.6 to 1.5 percent sulfur, less than 0.04 percent phosphorus, and the remainder ash. The best coke is in large lumps with sufficient strength to resist breakage during handling and descent through the blast furnace. Excessive porosity causes fuel losses. Most California coals are undesirable for coking because of their high ash content and the weakness of the resulting coke.

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[13] Arnold, Ralph, Coal in the Mt. Diablo Range, Monterey County, California: U. S. Geol. Survey Bull. 285, pp. 223-224, 1906.

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[15] Clark, S. G., Geology of the Covelo district, Mendocino County, California: Univ. Calif., Dept. Geol. Sci. Bull., vol. 25, pp. 119-143, 1941.

[16] Goodyear, W. A., Coal mines of the western coast of the United States, p. 75, A. L. Bancroft and Company, 1877.

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In 1948 the monthly blast-furnace coke yield at Fontana was 27,500 tons. This was produced from high-volatile coal from the company's Sunnyside mine in Utah, mixed with a few thousand tons of low-volatile coal from Arkansas. These high-volatile and low-volatile coals are blended at Fontana, low-volatile coal constituting 9 to 10 percent of the total. The blended coal is reduced to 1½-inch size, and some slaty impurities are removed. After further crushing, so that 50 percent passes a ⅛-inch screen, it is ready for coking.

The coke ovens at Fontana are of the under-jet by-product type capable of utilizing either coke-oven gas or blast-furnace gas.[2] The 90 ovens which the plant employs have a combined capacity of 933 tons of coke per day. A total of 296,749 tons of blast-furnace coke was produced during 1948. A comparable tonnage has been produced each year since 1943.[3]

Coke produced at the Fontana plant is used as blast-furnace fuel and in the open-hearth production of steel. The breeze is consumed as fuel in the sintering plant and for rebuilding the bottoms of the soaking pits.[4] Several hundred tons of breeze and small amounts of nut coke are sold each month.

Production costs at Fontana are slightly higher than in eastern coking plants. The operators at Fontana state that this cost difference is compensated, in part, by the superior quality of coke produced at the Fontana plant. Because of this higher quality the Fontana furnaces use less coke than the average eastern furnace. By-products of coking are recovered at the Fontana plant. They include ammonium sulfate, tar, creosote oil, distillate, phenol, fuel oil, benzol, tolnol, xylol, naphtha, and other light oil products.

Blast-furnace coke produced at Fontana is not usually sold on the open market; accordingly no price quotations are made. A considerable amount of coke that is produced elsewhere is consumed by open-hearth steel plants, foundries, non-ferrous smelters, and in various industrial plants in the state. By-product oven coke produced in the east sold for $17 to $22 per ton in December 1948.[5]

California's coke output, though important in the west, is small compared with the total United States production. More than 95 percent of United States coke is made from coal mined in the east, midwest, and south. Coking plants are located near centers of pig-iron production, which are mainly in Pennsylvania, Illinois, Ohio, New York, Indiana, and Alabama.

Coke is produced in the United States in beehive-type ovens as well as in the by-product type used at Fontana. In recent years the production of by-product process coke has greatly exceeded the production from beehive ovens. Coke consumed as blast-furnace fuel constitutes 80 percent of the annual United States coke production. The remaining 20 percent is used for household heating, in foundries, non-ferrous smelting, in many industrial and chemical processes, and in the manufacture of producer gas and water gas.[6]

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[2] Ramsey, G. D., The Fontana steel plant and raw materials supply: Mining and Metallurgy, vol. 25, pp. 423-426, Sept. 1944.

[3] Statistics by courtesy of F. M. Rich, Kaiser Company, Inc., Fontana, California.

[4] Powell, Kenneth, Raw material supplies for Kaiser steel, an address delivered to the Mining Committee, Los Angeles Chamber of Commerce, April 23, 1947.

[5] Production and stocks of coke: U. S. Bur. Mines Min. Ind. Surveys Monthly, Coke Rept. 250, Feb. 1949.

[6] DeCarlo, J. A., Corgan, J. A., and Otero, M. M., Coke and coke chemicals: Minerals Yearbook 1947, pp. 389-448, 1949.

NATURAL GAS

By Gordon B. Oakeshott

The use of natural gas in the United States, and particularly in California, has grown tremendously in the last few years. In 1947 natural gas supplied 15 to 16 percent of the total energy requirements of the United States, approximately four times the energy supplied by hydroelectric power.[1] This rapid growth in the use of natural gas, for both domestic and industrial purposes, is expected to continue for the next several years as pipe line facilities become available for transmission of gas from the fields to major centers of consumption. The six leading states in the production of natural gas—Texas, Louisiana, California, Oklahoma, West Virginia, and Kansas—produce nearly nine-tenths, and consume two-thirds of the natural gas marketed in the United States. For the United States as a whole, reserves of natural gas have been on the increase in the past few years, but very large requirements in California have necessitated importation, chiefly from Texas, by pipe line. At the beginning of 1948, the proven reserves of natural gas in California amounted to 10.2 trillion cubic feet, 6.1 percent of the United States reserve of 165.9 trillion cubic feet.[2]

Geologic Occurrence. Two types of natural gas, exclusive of carbon dioxide, are of commercial importance in California: (1) dry gas, or marsh gas, essentially separate from petroleum in occurrence, and (2) oil-well, petroleum, or wet gas, occurring in the same formations as petroleum and produced with it. The dry gas is a mixture composed of several hydrocarbons, methane (CH_4) being the chief among them, plus small percentages of carbon dioxide and nitrogen. Wet gas, after removal of the liquid petroleum, is similar in composition to dry gas, but is usually lower in methane. Because the composition of both types of gas varies considerably from one field to another, the heating value is also variable. Some compensation for variation in heating value is made by blending gases from several fields, particularly dry gas and oil-well gas when possible; oil-well gas generally has the higher heat value.

Geologic factors necessary for the formation and accumulation of natural gas are very similar to those for petroleum, namely: (1) a source rock high in organic matter, and (2) a structural or stratigraphic trap adequate to prevent the loss of the highly fluid gases. The organic source rocks, ranging in age from Upper Jurassic to Pliocene, are common in the Sacramento and San Joaquin Valleys and in the Coast Ranges. Gas-producing zones in California are all sandy beds (except for the Santa Maria district where petroleum production is from fractured Miocene chert) and are in rock formations of all ages ranging from Cretaceous to Pliocene. It is common to find gas zones above oil zones. Oil near the crest of a structure normally has a higher gas content than oil lower on the flanks of the same structure. No satisfactory geological explanation has been given for the occurrence of dry gas without oil, as in the Rio Vista and the other dry-gas fields. Nearly all gas production in the state is from closed anticlinal structures, including domes and asymmetrical anticlines. These are often faulted, and may or may not have topographic expression.

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[1] Western power and fuel outlook—2, natural gas: Federal Reserve Bank of San Francisco Monthly Rev., pp. 52-61, May 1949.

[2] Moulton, G. F., Gas for the future: Am. Assoc. Petroleum Geologists Bull., vol. 32, pp. 1808-1820, 1948.

Utilization. A large proportion of the natural gas marketed is consumed very close to the fields from which it is produced, although long-distance pipeline transmission is becoming more general. About 75 percent of the natural gas sold by utility companies in the San Francisco Bay area is dry gas (largely from the Rio Vista gas field in Sacramento, Solano, and Contra Costa Counties), while 90 percent of that utilized in the southern California consuming area is oil-well (wet) gas produced in the great oil fields of Los Angeles, Kern, Ventura, and Orange Counties.

The use of natural gas in the producing fields has always been large and, in the past, it has often been wasteful. Conservation methods in recent years have reduced wastage to a small figure. The use of natural gas in repressuring oil fields, to increase the ultimate recovery of oil, is growing. In this process gas is usually injected into the reservoir formation after the liquid fraction has been removed. A considerable amount of natural gas is also used by the oil companies as fuel for operating refineries.

In contrast with Texas and other gas-producing states, California uses little natural gas as a raw material for the chemical industries; the largest use is for fuel and heating purposes. Approximately three-quarters of all heated dwellings in California use gas. It is also very widely used in such industries as ceramics, glass, cement, power generation, food processing, and metal fabrication. Cheapness and constant availability are prime factors in these uses.

Figures on natural-gas sales in the United States show a present trend of rapid increase of natural-gas use for all purposes, but particularly for residential use.

Marketing Natural Gas in California.[3] The natural-gas industry is facing a very large and increasing demand for its product. Markets for natural gas at the present time appear to be almost unlimited. The industry increased its sales, in 1948, 11 percent over the previous year, and increased the number of gas customers in the same proportion. A major problem facing natural-gas producers and consumers is the construction of transmission lines and compressor stations needed to transport gas from the major producing areas to large centers of consumption. Natural-gas pipe line mileage has grown from 162,000 in the United States in 1933 to 251,330 in 1948. Construction expenditures in the industry have risen from $79,000,000 in 1938 to $236,750,000 in 1946, and $675,000,000 in 1948. A continuing scarcity of pipe steel may slow this expansion in 1949.

In California, the demand for natural gas has increased at an even more rapid rate than in the country as a whole, because of an extremely rapid growth in population and industry. Even though California is among the large gas-producing states, local supply is insufficient to meet demand, and gas must be imported from other states. Natural-gas production and utilization took its first big jump upward in 1908 when the industry really began in the state. Since that year rapid continuous expansion has taken place, except for set-backs during the depression

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[3] Western power and fuel outlook—2, *op. cit.*, May 1949.
Duff, D. M., Four-year natural-gas program to cost nearly two billion: Oil and Gas Jour., Jan. 27, 1949, pp. 229-233.

*Gas fields and pools—discovery and geologic data.**

County	Field	Year	Company	Well	Depth	Initial M cu. ft.	Structure†	Geologic age
Butte	Durham	46	Standard	Donohoe Fee 1	2,176	10,937	A	Eocene
Colusa	Colusa	43	General Pet.	Capital 1	2,940	4,500	A	Cretaceous
Contra Costa	Rio Vista (see Solano County)							
Glenn	Afton	44	Richfield	Afton Comm. 1-1	3,910	6,200	A	Cretaceous
	Ord Bend	43	Superior	Knight 1	3,690	5,040	A	Cretaceous
	Willows	38	Ohio	Willard 1	2,240	5,000	D	Cretaceous
Humboldt	Tompkins Hill	37	Texas	Eureka 2	5,480	1,500	A	Pliocene
Kern	Bowerbark	42	Texas	S. P. 47-15	4,262	10,000	A	Pliocene
	Buena Vista Hills	07	Honolulu	Well 10-1	1,608	50,000	A	Pliocene
	Buttonwillow	27	Milham Expl.	Kern 1-A	2,648	11,700	A	Pliocene
	Coles Levee, North	41	Richfield	K. C. L. 1-G-28	5,149	11,800	A	Pliocene
	Coles Levee, South	41	Standard	K. C. L. 20-9	5,136	8,894	A	Pliocene
	Elk Hills	19	Pacific	Hay 5	1,919	N. A.	A	Pliocene
	Paloma	34	Ohio	K. C. L. A-1	5,250	9,000	FA	Pliocene
	Semitropic							
	Hill sand	35	Standard	Hill 1	3,200	107,000	A	Pliocene
	Mya sand	35	Fullerton	No. 24-14	2,463	10,000	A	Pliocene
	Trico (partly in Kings and Tulare Counties)							
	South Mya	34	Trico	Well 2	2,476	Blew out	A	Pliocene
	North Mya	46	G. B. Finch	Finch 2	2,571	5,000	A	Pliocene
	Atwill	45	Trico	Atwill Comm. 1	3,238	24,000	A	Pliocene
Kings	Alpaugh	44	Standard	Cutter Unit 1	3,510	14,388	A	Pliocene
Los Angeles	El Segundo	40	Ohio	Gough 12	3,867	10,000	A	Pliocene
Madera	Chowchilla							
	Upper	36	Pure	Chowchilla 2	2,606	15,000	D	Eocene
	Lower	34	Pure	Chowchilla 1	8,377	20,000	D	Cretaceous
	Gill Ranch	43	Texas	Gill 38-16	4,517	11,000	FA	Eocene
	Moffatt	43	Texas	Moffatt 1-7	3,965	7,070	A	Eocene
Sacramento	Rio Vista (See Solano County)							
	Thornton	43	Amerada Pet.	Capital Land 1	3,380	6,800	A	Eocene

San Joaquin	Lodi	43	Amerada Pet.	Lodi Comm. 9-1	2,270	7,200	A	Eocene
	McDonald Is.	36	Standard	McDonald 1	5,227	20,647	D	Eocene
	Roberts Is.	42	Standard	Woods Comm. 1	5,254	5,613	A	Eocene
	Tracy	35	Amerada Pet.	F. D. L. 2	4,063	35,000	A	Cretaceous
	Vernalis (partly in Stanislaus County)	41	Standard	Blewett 1	3,872	10,000	A	Cretaceous
Santa Barbara	Goleta	29	Gereral Pet.	More 1	4,273	35,000	FA	Miocene
	Refugio	47	Rothschild	Orella 1	3,119	5,000	FA	Miocene
	Summerland	48	Standard	Williams 1	3,700	2,155	A	Oligocene
Solano	Cache Slough	45	Standard	Cal. Pack 2	4,840	14,867	A	Eocene
	Denverton	48	Honolulu	McCormick Est. 1	3,010	7,000	A	Eocene
	Honker	44	Standard	Honker Comm. 1-A	7,246	3,200	FA	Eocene
	Kirby Hill							
	Lambie	45	Shell	Lambie 1-A	2,320	3,980	FA	Eocene
	Lambie 5	48	Shell	Lambie 5	4,232	4,720	FA	Cretaceous
	Maine Prairie	45	Amerada Pet.	Wineman 1	1,790	18,997	FA	Eocene
	Maine Prairie, North	46	Amerada Pet.	Winship 1-A	4,805	7,210	A	Eocene
	Millar	44	Amerada Pet.	Starkey Fee 1	4,620	22,750	A	Eocene
	Potrero Hills	38	Richfield	Potrero Hills 1	3,265	5,000	A	Cretaceous
	Rio Vista (part also in Sacramento and Contra Costa Counties)							
	Anderson Sd.	44	Standard	Perry Anderson H-6	5,795	15,704	FA	Eocene
	Emigh Sd.	36	Amerada Pet.	Emigh 1	4,485	50,000	FA	Eocene
	Hamilton Sd.	36	Amerada Pet.	Hamilton 1	5,600	4,350	FA	Eocene
	Midland Sd.	43	Standard	Midland Fee 5	5,082	13,337	FA	Eocene
	Suisun Bay	44	Standard	Suisun Comm. 3	3,978	7,350	FA	Eocene
Sonoma	Petaluma	41	Trico	Miller 1	1,214	8,000	A	Pliocene
Sutter	Marysville Buttes	33	Buttes Oilfields	Well 1	2,727	3,425	Complex	U. Cretaceous
Tehama	Corning	44	Superior	Saldubehere 1	3,954	17,676	A	Cretaceous
Yolo	Dunnigan Hills	46	Texas	Hermle 1	2,620	3,030	A	Eocene
	Fairfield Knolls	37	Standard	Hooper 1	3,700	7,310	A	Cretaceous
	Pleasant Creek	48	Shell	Unit 3-1	3,000	9,500	A	Paleocene (Martinez)
	Winters	46	Shell	McCune 1	5,240	11,000	A	Cretaceous

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* Modified from Petroleum World Annual Review 1949. Division of Mines Bulletin 118 (1943) contains descriptions of all California gas fields discovered prior to its publication. No major discoveries have been made since 1936.

† A = Anticline. FA = Faulted anticline. D = Dome.

*Utilization of natural gas in California, 1936-47 * (billions of cubic feet, annual basis, rounded).*

	Total current production [1]	Industrial use						Domestic and commercial	Unaccounted for	
		Total industrial	Oil-company use			Electric power	Other industrial [4]		Field waste	Gas company
			Total	Field [2]	Other [3]					
1936	323	217	119	84	35	21	77	71	24	11
1937	333	219	120	83	38	16	83	83	19	12
1938	352	215	126	87	39	9	80	86	38	12
1939	353	216	105	82	22	23	89	91	33	13
1940	360	223	112	89	23	13	97	94	30	13
1941	369	234	110	86	24	12	112	108	14	14
1942	396	244	108	67	40	12	124	129	7	16
1943	445	291	128	69	59	32	131	137	7	10
1944	519	335	160	90	70	49	127	160	10	14
1945	523	323	171	93	78	26	126	172	14	14
1946	503	288	150	93	57	18	120	184	12	12
1947	[a] 557	333	161	91	70	40	133	193	12	18

* California natural gas production and utilization, Federal Power Commission, Docket G-1079, Exhibit 132, Witness R. M. Bauer, p. 11, as reproduced in Federal Reserve Bank of San Francisco, Monthly Rev., May 1949.

[1] Net withdrawals from formation and underground storage.
[2] Field fuel, drilling fuel, and gasoline plant fuel.
[3] Refinery and pump station fuel.
[4] Includes gas companies' own use.
[a] Including 3.5 billion cubic feet from Texas pipe line.

*Natural-gas sales in the United States (M cu. ft.) (preliminary estimate).**

	1947	1948	Percent increase
Total	2,515,251,000	2,802,079,200	11.4
Residential	740,572,000	881,830,600	19.1
Commercial	224,295,000	262,071,600	16.8
Industrial	1,467,504,000	1,558,652,800	6.2
Other	82,880,000	99,524,200	

* Duff, Dahl M., Four-year natural-gas program to cost nearly two billion: Oil and Gas Jour., Jan. 27, 1949, pp. 229-233.

years of the middle twenties, and again in the early thirties. At the end of 1948, there were 2,500,000 customers being served through 26,000 miles of pipe line in California, and the natural-gas industry was valued at about $500,000,000.

*Number of natural-gas customers in California.**

Year	Northern California [1]	Southern California	Total
1935			1,486,640
1936			1,547,310
1937	593,703	988,967	1,582,670
1938	613,779	1,025,263	1,639,042
1939	644,655	1,069,593	1,714,248
1940	670,579	1,126,713	1,797,292
1941	710,221	1,198,711	1,908,932
1942	742,524	1,233,381	1,975,905
1943	763,007	1,271,488	2,034,495
1944	785,860	1,305,240	2,091,100
1945	804,906	1,337,736	2,142,642
1946	836,670	1,387,285	2,223,955
1947	890,787	1,480,616	2,371,403
1948	950,484	1,591,116	2,541,600

* Data from Petroleum World Annual Review 1949. Figures are for the end of each year.

[1] North of Fresno and Paso Robles.

The importance of petroleum and natural gas in the economy of California is indicated in the fact that, together, they supply close to 97 percent of the total energy requirements of the state, whereas they supply only 50 percent of the total energy requirements for the United States as a whole. The industrial use of natural gas alone in California is larger than that of fuel oil in all the other western states combined.

Public-utility gas sales may be classed as residential, commercial, and industrial. Highest rates are paid by residential users. Commercial users, because of the larger volume of consumption, have lower rates. Industrial users pay the lowest rates because they accept limited service at times of greatest demand. However, rates to industrial users have been greatly increased in the last few years in California, while residential and commercial rates have been coming down. The average rate for utility sales to residential and commercial customers declined from 57 to 54 cents per thousand cubic feet in California between 1945 and 1948. At the same time, rates to industrial customers increased from an average 15.5 cents to 31 cents per thousand cubic feet.

Extremely low rates for surplus natural gas, which was produced in great quantities with oil, were offered in the late twenties. The attractive prices put natural gas in a strong competitive position with fuel oil and other sources of power. As a result, there was a widespread conversion of fuel equipment to the use of gas, and a rapid increase in the number of domestic consumers. By 1940 a bottom price of about seven cents per thousand cubic feet was paid to producers in the field. Gas companies in California obtain their gas from producers in the fields and from pipe line companies, but generally do not own gas wells. Since most of the gas has been associated with oil production, the price of natural gas has often been linked to the posted price of fuel oil. OPA froze the price of gas during the late war, but allowed increases in fuel oil prices. This maintained a situation favorable to increased use of gas.

*Average revenue to the utilities from sales of natural gas (cents per thousand cubic feet).**

Year	General service	Firm industrial (uninterruptible)	Surplus (interruptible)
1942	62	28	14
1945	57	28	14
1946	55.5	32	17
1947	56	37	25
1948	54	37	31

* Western power and fuel outlook—2, op. cit., p. 61. Data from California Public Utilities Commission.

In spite of the large increase in cost to industrial interruptible-service gas users, the cost of gas is still somewhat below the cost of equivalent fuel oil. Recent provisions by the California Public Utilities Commission have had some influence in setting an effective ceiling on the cost of this type of service.

An increasing need for imported gas from other states and an extension of transmission lines within the state are factors influencing rising gas rates. For example, the largest gas utility company in northern California now estimates the cost of imported gas delivered to the San Francisco Bay area at approximately 24 or 25 cents per thousand cubic feet. Several applications for increased utility rates are pending before the California Public Utilities Commission. In general, these proposals contemplate average increases of 12 or 13 percent.

Production and Reserves. The first useful natural gas produced in California was from the courthouse well at Stockton, drilled to a depth of 1,003 feet in 1854-58; many wells in the Stockton area have since encountered gas in drilling for water. Gas discovered in water wells in 1891 near Sacramento has also been used. A gas well drilled at Briceland, Humboldt County, in 1894 furnished the natural gas for that small town for many years. In 1901 a well was completed in Solano County which supplied gas to the towns of Suisun and Fairfield. The first high-pressure gas well in northern California to be brought in was at Marysville Buttes, Sutter County, in 1933, by Buttes Oilfields, Inc. The well produced an initial 3,425 thousand cubic feet per day from a depth of 2,727 feet.

In June 1936, the Rio Vista gas field was brought in by Amerada Petroleum Corporation. The discovery well produced 50,000 thousand cubic feet per day from Eocene sand at a depth of 4,485 feet. Rio Vista is now the largest gas-producing field in California; it produced more gas in 1948 than the next two largest fields (Kettleman North Dome and Wilmington) combined. Rio Vista had 143 wells which were producing in August 1948. Discovery and early development was in Solano County; but later development spread southeastward across the Sacramento River into Sacramento County, and, more recently, across the San Joaquin River into Contra Costa County. Sacramento County production has exceeded that of Solano County since 1941. Discovery of two deeper gas sands in 1943 and 1944 added appreciably to the reserves of the field.

An intensive search for gas, which has gone on in northern California in the past few years, has resulted in a number of new field discoveries since Rio Vista. These include Durham, Colusa, Glenn, Ord Bend, Willows, Tompkins Hill (Eureka gas), Thornton, Lodi, Roberts Island, Vernalis, Cache Slough, Denverton, Honker, Kirby Hill, Maine Prairie, Millar, Potrero Hills, Suisun, Petaluma, Corning, Dunningan Hills, Fairfield Knolls, Pleasant Creek, and Winters. The majority of these have proved disappointingly small, and have added almost nothing to reserves of the state. Of those named, Tompkins Hill (Eureka gas), Thornton, Lodi, Vernalis, and Kirby Hill are successful small dry-gas fields. McDonald Island, discovered in 1936, is second in importance to Rio Vista, but only has 4 or 5 percent of Rio Vista's reserves.

Most of the gas produced in southern California has been wet gas produced with oil; consequently the production histories of the gas and oil are closely related. The largest gas-producing oil fields, in order, are: Kettleman North Dome, Wilmington, Ventura, East Coalinga Extension,

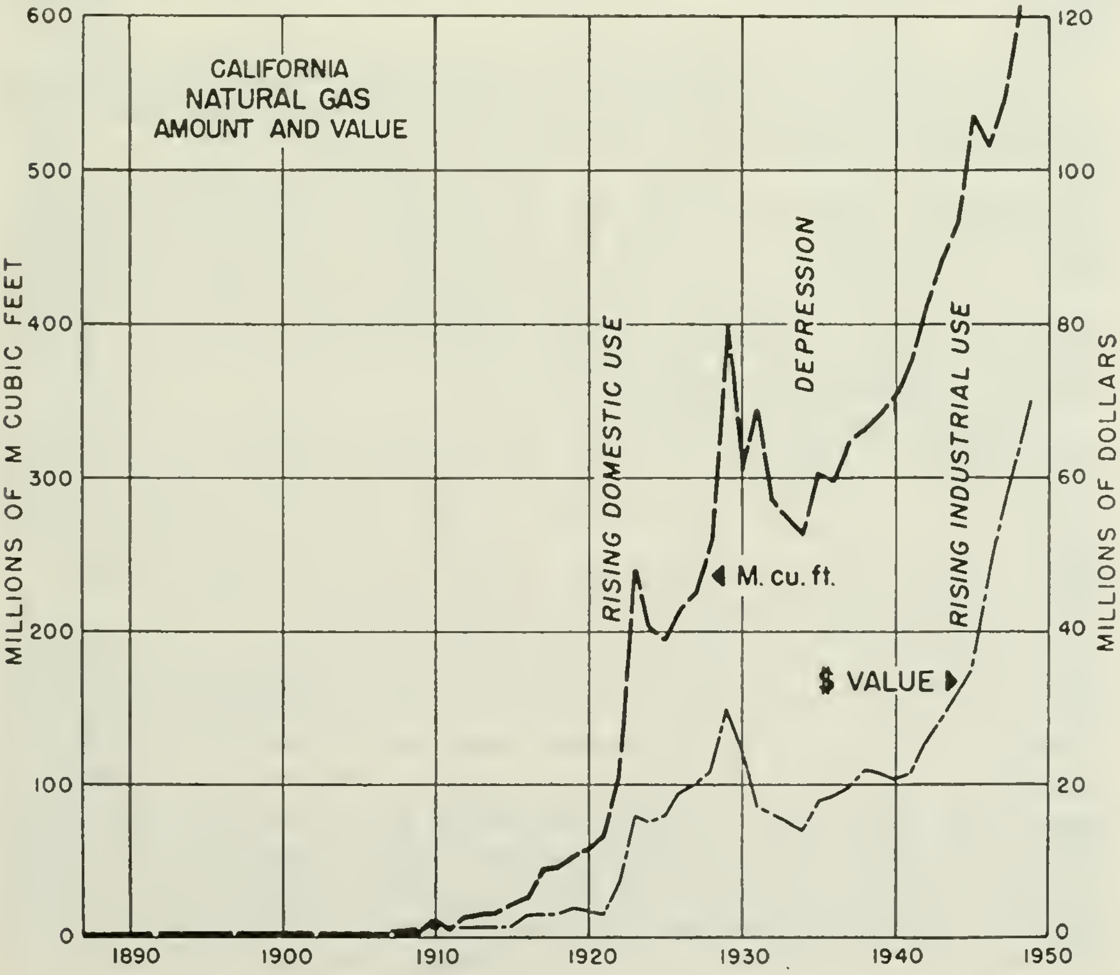

FIGURE 1. Chart showing amount and value of natural gas produced in California, 1888-1948.

Cymric, Huntington Beach, Midway-Sunset, Santa Maria Valley, and Belridge North. Midway-Sunset, discovered in 1901, is the oldest of this group of major gas-producing oil fields and has had the largest cumulative production of petroleum of any oil field in the state. The latest discovery of the group was East Coalinga Extension, discovered in 1938. Kettleman North Dome, discovered in 1928, is second only to Rio Vista in gas reserves.

Southern California dry-gas fields include Paloma, Trico, Bowerbank, Semitropic, and Buttonwillow. Paloma, the largest, has a reserve amounting to less than one-third that of Rio Vista. Trico is next in importance with a reserve of approximately one-tenth that of Rio Vista.

*Largest natural-gas producing fields in California in 1948.**

Field	Net gas withdrawn in 1948 in M cu. ft.
Rio Vista gas	138,977,851
Kettleman North Dome	75,340,766
Wilmington	55,920,765
Ventura	35,059,866
East Coalinga Extension	29,714,099
Cymric	20,391,132
Huntington Beach	16,959,041
Midway-Sunset	15,995,444
Santa Maria Valley	13,824,751
Belridge North	12,427,695
Paloma	12,183,475
Trico gas	10,672,438

* Figures are for net gas withdrawn as reported by State Division of Oil and Gas. Those shown had a net gas withdrawal, for the year, of more than 10,000,000 M cu. ft. Some fields returned a large amount of gas to formation by gas injection.

The fields are similar in that they are structural domes and produce nearly pure methane from the San Joaquin clay formation. Buttonwillow was discovered in 1927 through observation of a gentle topographic high. This was before the general use of geophysical exploration methods. All later dry-gas fields of any importance in California were located largely by seismographic exploration.

It is significant that, in spite of intensive exploration and numerous discoveries, no major gas fields have been found in California since Rio Vista in 1936. Additions to reserves have come mainly from extensions and from new pools in known fields. Total natural-gas reserves in the state declined from 10,232,980,306 thousand cubic feet on January 1, 1948 to 9,669,647,936 thousand cubic feet on January 1, 1949.

Summary and Outlook. Natural gas is second in value only to petroleum, among the mineral commodities found in California. The use of natural gas for residential, commercial, and industrial purposes began a strong upsurge in the early twenties which has continued to the present, except for a recession during the depression years of the thirties. In general, the state has two great centers of gas production: Rio Vista and smaller dry-gas fields in the Sacramento-San Joaquin delta region, the major source of natural gas used in the San Francisco Bay metropolitan area; and the numerous oil fields of southern California which feed natural oil-well gas into the Los Angeles metropolitan area.

*Natural gas utilized in California during 1948, by counties.**

County	M cu. ft.	Cents per M cu. ft.	Value
Butte	131,270	13	$17,065
Colusa	----------		----------
Contra Costa	2,499,960	15.5	387,494
Fresno	73,230,626	11.5	8,421,522
Glenn	1,511,627	15	226,744
Humboldt	1,174,300	10	117,430
Kern	89,170,919	11	9,808,801
Kings	42,385,979	12.5	5,298,247
Los Angeles	108,076,935	12.5	13,509,616
Madera	2,915,744	10	291,574
Orange	32,432,168	12	3,891,860
Sacramento	81,790,709	15.5	12,677,560
San Joaquin	8,277,153	18.5	1,531,273
San Luis Obispo	----------	--	----------
Santa Barbara	21,376,488	10.5	2,244,531
Solano	66,211,959	15.4	10,196,642
Sonoma	4,420	10	442
Stanislaus	126,750	17	21,548
Sutter	679,440	13	88,327
Tehama	----------	----------	----------
Tulare	10,672,438	16	1,707,590
Ventura	48,393,976	10.5	5,081,367
Yolo	222,230	13	28,890
Totals	591,285,091	----------	$75,548,523

* Data from State Division of Oil and Gas.

Natural-gas reserves in the state are large, amounting to 6 percent of the national total. There was a slight decrease in California reserves during the past year, in contrast to an increase in reserves in the United States as a whole. Discoveries of small new fields and new pools, and extensions of existing fields have been numerous, but no major gas field has been discovered in California in the last 13 years. Gas production has been increased year by year; 1948 production was the largest on record in terms of volume and value.

In spite of accelerated gas production, demand now exceeds the California supply and natural gas must be imported by pipe line from Texas, New Mexico, and other states. Natural-gas rates for all types of users are increasing, a trend that promises to continue, because of declining California reserves, greater domestic demand, and high cost of building the transmission lines to carry gas greater distances from production to consuming centers.

At the end of 1948, the gas industry in California was in the midst of a greatly expanded program of pipe line transmission and storage within the state, and import of natural gas from out of state. A major problem in expansion of the industry is the continued shortage of steel for manufacture of pipe.[4]

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[4] Evidence of progress in solution of this problem is found in two announcements made in August 1949: (1) A 1600-mile 34-inch pipe line is being constructed jointly by the Pacific Gas and Electric Company of California and El Paso Natural Gas Company of Texas. It will bring gas from Texas and New Mexico at a rate of 150 million cubic feet per day, beginning in January 1951. This rate is to be stepped up to 300 million cubic feet in 1952. The steel pipe is being manufactured in South San Francisco. (2) The Basalt Rock Company, early in 1950, will begin making expanded electric-fusion-weld steel pipe 22 to 36 inches in diameter, in the large amounts needed by the oil and gas industries. Plate from Kaiser's Fontana mill will be manufactured into pipe at the Napa plant of Basalt Rock Company and will be marketed by Kaiser as Basalt-Kaiser steel pipe.

*Annual volume and value of natural gas produced in California, 1888-1948.**

Year	M cu. ft.	Value	Year	M cu. ft.	Value
1888	12,000	$10,000	1919	52,173,503	$4,041,217
1889	14,500	12,680	1920	58,567,772	3,898,286
1890	41,250	33,000	1921	67,043,797	4,704,678
1891	39,000	30,000	1922	103,628,027	6,990,030
1892	75,000	55,000	1923	240,405,397	15,661,433
1893	84,000	68,500	1924	209,021,596	15,153,140
1894	85,000	75,000	1925	194,719,924	15,890,082
1895	110,000	100,000	1926	214,549,477	19,465,347
1896	131,000	110,157	1927	224,686,940	20,447,294
1897	71,300	62,657	1928	260,887,116	22,260,947
1898	111,165	74,424	1929	400,129,201	29,675,546
1899	115,110	95,000	1930	315,513,952	24,559,840
1900	40,566	34,578	1931	344,959,920	16,690,695
1901	120,800	92,034	1932	284,168,872	16,272,061
1902	120,968	99,443	1933	271,743,544	15,403,514
1903	120,134	75,237	1934	263,207,517	14,408,761
1904	144,437	91,035	1935	302,447,193	17,680,661
1905	148,345	102,479	1936	298,922,708	18,585,970
1906	168,175	109,489	1937	323,883,714	19,859,865
1907	169,991	114,759	1938	332,358,439	22,310,755
1908	842,883	474,584	1939	340,754,804	21,551,646
1909	1,148,467	616,932	1940	352,871,945	20,618,983
1910	10,579,933	1,676,367	1941	378,173,737	21,522,445
1911	5,000,000	491,859	1942	413,180,942	25,698,052
1912	12,600,000	940,076	1943	443,219,847	28,046,729
1913	14,210,836	1,053,292	1944	467,743,258	31,797,418
1914	16,529,963	1,049,470	1945	538,273,934	35,362,313
1915	21,992,892	1,706,480	1946	516,263,710	46,905,877
1916	28,134,365	2,871,751	1947	544,950,000	55,694,000
1917	44,343,020	2,964,922	1948	570,954,000	[1] 64,803,000
1918	46,373,052	3,289,524			

* Volume estimated from values for years 1888-98 and 1911-12 as some operators reported values only. Statistical bulletins prior to 1933 included carbon dioxide with natural gas. Figures for 1947-48 were supplied by U. S. Bur. Mines. All prior figures were supplied by State Division of Oil and Gas.

[1] Value shown is estimated value at well. The U. S. Bur. Mines reports the 1948 California consumption of natural gas as 617,615,000 M cu. ft., for which the consumer paid $206,885,000.

Natural-gas withdrawals and reserves by fields.[a]

Field	Net gas withdrawn Jan. to Dec. 1948 M cu. ft.	Gas reserves Jan. 1, 1948 M cu. ft.	Gas reserves Jan. 1, 1949 M cu. ft.
Dist. 1			
Aliso Canyon	780,547	63,736,870	62,956,323
Beverly Hills*	3,870	0	0
Brea-Olinda	[4] 4,831,792	44,150,855	39,319,063
Coyote—East	1,207,693	12,850,932	11,643,239
Coyote—West	8,896,088	67,614,572	58,718,484
Del Valle	6,224,739	38,118,550	31,893,811
Dominguez	7,095,591	32,484,957	25,389,566
El Segurdo	361,513	9,496,280	[3] 9,134,767
Huntington Beach	16,959,040	81,618,482	64,659,604
Inglewood	3,917,175	18,195,066	14,277,891
Lawndale	2,555,508	0	4,691,077
Long Beach	6,758,705	75,346,149	68,585,200
East Los Angeles	593,869	8,548,372	7,954,503
Montebello	2,916,872	28,706,756	25,789,868
Newhall*	22,771	0	0
Newhall-Potrero	1,670,504	146,402,925	144,732,421
Newport*	0	0	0

Natural-gas withdrawals and reserves by fields [a]*—Continued.*

Field	Net gas withdrawn Jan. to Dec. 1948 M cu. ft.	Gas reserves Jan. 1, 1948 M cu. ft.	Gas reserves Jan. 1, 1949 M cu. ft.
Dist. 1—Continued			
Newport, West	1,307,705	9,978,197	8,670,466
Newport, West—Gas*	31,946	0	0
Oak Canyon	913,702	25,514,192	25,690,490
Playa del Rey	759,879	4,500,000	3,740,124
Playa del Rey	[2] 295,770	[2] 3,256,623	[1] 3,552,393
Potrero	3,555,311	15,250,668	11,695,357
Richfield	1,749,363	18,141,671	16,391,708
Rosecrans	3,209,014	28,441,711	24,232,697
Salt Lake*	0	0	0
Santa Fe Springs	5,037,435	49,518,146	44,480,711
Seal Beach	3,248,749	17,614,691	14,385,912
Torrance	1,523,935	14,762,763	13,238,786
Turnbull	28,003	161,326	133,323
Whittier	198,158	1,818,249	1,620,091
Wilmington	55,920,765	355,758,491	299,838,392
Los Angeles County:			
Alondra Area	145,902	4,180,465	4,034,563
East Dominguez Area*	16,105	0	0
Hyperion Area*	17,927	0	0
Leffingwell Area*	10,882	0	0
Northwest Rosecrans Area*	118,686	0	0
Simi Area*	329	0	0
Orange County:			
Buena Park Area*	4,472	0	0
Talbert Area*	3,435	0	0
San Bernardino County:			
Chino-Mahala Area*	77	0	0
Totals	142,302,887	1,176,167,959	1,041,360,860
Dist. 2			
Bardsdale	1,451,419	2,744,136	8,300,000
Montalvo, West*	479,147	--------	--------
Ojai*	88,581	--------	--------
Oxnard*	244,668	--------	--------
Piru	1,447,821	--------	--------
Rincon	7,616,429	119,092,011	111,475,582
Santa Paula*	3,178	--------	--------
Sespe*	9,293	--------	--------
Simi*	7,459	--------	--------
South Mountain	3,062,559	2,633,905	19,200,000
Ventura	35,059,866	683,030,318	647,970,452
Totals	49,470,420	807,500,370	786,946,034
Dist. 3			
Arroyo Grande*	873	--------	0
Capitan	946,666	4,957,683	4,011,017
Casmalia*	116,811	0	0
Cat Canyon	1,474,102	19,246,856	17,772,754
Elwood	1,108,179	9,919,227	8,811,048
La Goleta Gas	2,223,226	42,268,025	40,044,799
Lompoc	679,053	9,673,193	8,994,140
Orcutt	2,765,526	10,643,631	7,878,105
Russell Ranch*	310,958	--------	0
San Ardo	7,517	--------	0
Santa Maria Valley	13,824,751	23,767,334	[5] 28,195,244
Summerland	14,845	--------	0
Santa Barbara County:			
Refugio Area	94,253	0	0
Miscellaneous	17,672	--------	0
Totals	23,584,432	120,475,949	97,454,446

Natural-gas withdrawals and reserves by fields [a]*—Continued.*

Field	Net gas withdrawn Jan. to Dec. 1948 M cu. ft.	Gas reserves Jan. 1, 1948 M cu. ft.	Gas reserves Jan. 1, 1949 M cu. ft.
Dist. 4			
Antelope Hills	200,900	6,903,666	6,702,766
Ant Hill	17,217	80,000	62,783
Belridge, North:			
Shallow Zone	4,396	75,000	70,604
Temblor Zone [1]	[2] 8,574,849	10,742,073	19,316,922
"R" Zone	2,586,423	64,720,233	62,133,810
Wagonwheel Zone	18,239,551	13,024,965	75,974,528
"Y" Zone	172,174	4,143,310	3,971,136
Belridge, South	835,747	1,500,000	664,253
Blackwells Corner	7,200	250,000	242,800
Canal	1,206,102	36,823,734	35,617,632
Canfield Ranch	8,866	55,000	46,134
Coles Levee, North	[2] 1,152,584	365,609,875	366,762,459
Coles Levee, North, Gas	517,223	6,851,759	6,334,536
Coles Levee, South	1,816,542	559,010,126	557,193,584
Coles Levee, South, Gas	2,152,543	6,071,762	3,919,219
Cymric:			
Upper Zones*	2,347,484	0	0
Oceanic Zone	13,032,048	17,215,618	4,183,570
Point of Rocks Zone	5,011,600	8,529,562	3,517,962
Devils Den*	1,659	----------	0
Edison	2,312,409	9,000,000	6,687,591
Elk Hills—All Zones	[2] 65,616	588,896,015	587,956,288
Elk Hills, Gas	†1,576,467	0	0
Elk Hills, Upper	[2] †150,100	----------	0
Elk Hills, Stevens	†87,566	0	0
Fruitvale	436,184	2,500,000	2,063,816
Greeley	1,537,210	116,072,972	114,535,762
Kern Front	441,155	4,500,000	4,058,845
Kern River	10,476	65,000	54,524
Lost Hills	1,546,753	6,200,000	4,653,247
McKittrick-Temblor*	509,611	0	0
Midway-Sunset	15,995,444	89,990,460	**73,998,086
Midway-Sunset, Buena Vista Gas	1,826,510	8,726,524	**6,896,968
Mt. Poso	75,775	110,000	34,225
Mountain View	1,406,217	1,139,909	1,350,894
Paloma—All Zones	12,183,475	632,210,168	619,439,249
Paloma, Gas	9,025	0	0
Paloma, Symons Zone	†1,035,325	0	0
Paloma, Paloma Zone	†6,233,285	----------	0
Poso Creek	101,849	360,000	258,151
Rio Bravo	1,721,324	152,994,313	151,272,989
Round Mountain	6,383	100,000	93,617
Strand	166,959	10,166,846	9,999,887
Strand, East	239,175	4,121,168	3,881,993
Tejon	373,069	1,500,000	1,126,931
Ten Section	9,095,293	99,703,711	90,608,418
Wasco	44,436	244,766	200,330
Wheeler Ridge	71,159	260,000	188,841
Kern County:			
Bacon Hills Area*	341,462	0	0
Bellevue Area*	66,368	0	0
Comanche Point*	25	0	0
McDonald Anticline Area	24	0	0
McClung Area	0	3,500	3,500
Bowerbank Gas	485,443	34,191,470	33,706,027
Buttonwillow Gas	521,399	600,000	78,601
Semitropic Gas	902,296	11,392,402	10,490,106
Trico Gas	10,672,438	217,135,335	206,462,897
Totals	103,047,734	3,093,791,242	3,076,816,481

Natural-gas withdrawals and reserves by fields [a]—Continued.

Field	Net gas withdrawn Jan. to Dec. 1948 M cu. ft.	Gas reserves Jan. 1, 1948 M cu. ft.	Gas reserves Jan. 1, 1949 M cu. ft.
Dist. 5			
Coalinga*	1,202,389	0	0
East Coalinga Extension	29,714,099	524,478,318	494,764,219
Guijarral Hills*	59,075	----------	0
Helm	5,195,914	200,654,828	195,458,914
Jacalitos	2,036,979	12,107,615	10,070,636
Kettleman Middle Dome*	486,054	0	0
Kettleman North Dome	75,340,766	1,702,839,833	1,627,499,067
Pleasant Valley	1,312,648	18,375,190	17,062,542
Pyramid Hills*	10,328	0	0
Raisin City	754,747	5,242,173	4,487,426
Riverdale	2,174,979	28,653,637	26,478,658
Afton Gas*	637,431	0	0
Cache Slough Gas*	2,558,328	0	0
Eureka Gas	1,174,300	47,841,371	46,667,071
Fairfield Knolls Gas*	222,237	0	0
Gill Ranch Gas	2,771,215	32,500,556	29,729,341
Kirby Hill Gas	3,237,021	0	35,165,774
Lodi Gas	1,143,072	2,197,818	1,054,746
Maine Prarie Gas*	1,957,236	0	0
Marysville Buttes Gas	685,449	148,433,892	16,078,275
McDonald Island Gas	5,579,652	94,136,604	88,556,952
Millar Gas*	2,843,601	0	0
Ord Bend Gas*	874,196	0	0
Rio Vista Gas	138,977,851	2,155,458,154	2,016,480,303
Roberts Island Gas*	304,852	0	0
Suisun Bay Gas*	2,971,397	0	0
Thornton Gas	3,410,823	24,372,916	20,962,093
Tracy Gas	262,724	10,672,789	10,410,065
Vernalis Gas	935,059	7,028,092	6,093,033
Butte County:			
Chico Area*	132,196	0	0
Durham Area*	1,034	0	0
Fresno County:			
Burrel Area*	3,209	0	0
Cheney Ranch Area*	51,563	0	0
San Joaquin Area*	37,732	0	0
Kings County:			
Trico N. W. Area*	226,082	0	0
Madera County:			
Chowchilla Area	0	20,051,000	20,051,000
Moffatt Ranch Area*	149,529	0	0
San Joaquin County:			
Galt Area*	169,541	0	0
Solano County:			
Denverton Area*	33,373	-	0
Honker Area*	2,799	0	0
Sonoma County:			
Petaluma Area*	4,382	- - -	0
Yolo County:			
Dunnigan Hills Area*	1,379	0	0
Winters Area*	520	----------	0
Totals	289,653,709	5,035,044,786	4,667,070,115
Grand totals	608,059,182	10,232,980,306	9,669,647,936

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[a] Data from State Division of Oil and Gas.

* No reserves estimated because of lack of data or because they are insufficient to justify pipe line connections to marketing system for domestic or industrial consumption.

** Corrected figure.

† Not included in totals.

[1] Storage only.

[2] Net storage.

[3] Dry gas estimate only.

[4] Includes 47,331 M cu. ft. gas withdrawn from underground storage.

[5] Re-estimate.

[6] Preliminary estimate.

NATURAL GASOLINE AND LIQUEFIED PETROLEUM GASES

By Gordon B. Oakeshott

The production of natural gasoline and liquid petroleum products from petroleum and gas wells in California has been generally on the increase for many years. Natural-gas liquids now rank second in value of mineral commodities produced in the state, and are exceeded only by petroleum. The trends are strongly toward increasing demand and higher production during the next few years, although California reserves of natural-gas liquids have shown some evidences of decline.

Definition. Natural gas obtained from the oil and gas wells of California varies in composition from ''dry'' to ''wet.'' Dry gas consists largely of methane (CH_4) with little or no liquid hydrocarbon compounds present. Wet gas contains varying amounts of hydrocarbon compounds which are ordinarily removed, processed at the field, and sold separately. Natural-gas liquids are those hydrocarbons in liquid form which are obtained by absorption or condensation from natural gas. The principal liquids so obtained are grouped as natural gasoline, condensate, and liquified pretroleum gases. The average liquid yield from California natural gas is a little more than one barrel per thousand cubic feet of gas.

Occurrence and Composition. The natural gas which yields most liquid is that which is dissolved with crude oil in the subsurface reservoir, although much liquid-bearing gas is not actually dissolved in oil but is in contact with it. Dry gas, not associated with oil in the reservoir, yields the least natural-gas liquid.

Processing of the natural gas is carried on at natural-gasoline and cycle plants located at or near the producing fields. The products obtained from natural-gasoline plants are various hydrocarbons and mixtures of hydrocarbons. These products (listed here in the order of amount produced) are classified commercially as (1) natural gasoline and natural-gasoline mixtures, (2) raw condensate, (3) normal butane, (4) finished gasoline and naphtha, (5) commercial butane-propane mixture, (6) propane, (7) isobutane, (8) other mixture (liquefied petroleum gases), and (10) other products.

Producing Fields. The three major natural-gas-liquid producing regions in California are the Los Angeles Basin, the southern San Joaquin Valley, and the coastal region including Ventura and Santa Barbara Counties. Production is greatest from the Los Angeles area, least from the coastal region. The 10 largest natural-gasoline producing fields in 1948 were, in order, (1) Kettleman Hills, (2) Wilmington, (3) Ventura Avenue, (4) Huntington Beach, (5) Long Beach, (6) Santa Fe Springs, (7) Coyote West, (8) Brea-Olinda, (9) Dominguez, and (10) Coalinga-Pleasant Valley. Two fields, Paloma and South Coles Levee, produced the largest amounts of condensate.

Natural-Gasoline and Cycle Plants. The processing of natural gas to obtain the natural-gas liquids is done by natural-gasoline and cycle plants located in or close to the producing fields. These plants do the field processing of wet gas and take part in repressuring of underground reservoirs. The natural-gasoline plants are the most extensive of field-located processing operations. Cycling operations inject stripped gas into the producing formation to force condensate-bearing gas in the reservoir to the wells to allow full recovery of condensate. It is an operation of increasing importance in securing maximum recovery of light hydrocarbons. Cycle plants produce the product called "cycle condensate."

On January 1, 1949,[1] there were 72 natural-gasoline and two cycle plants operating in California with a total daily capacity of 2,894,000 gallons natural gasoline, 1,173,800 gallons liquefied petroleum gases (blended butane and propane), and 430,500 gallons cycle condensate. On the same date in 1948 there were 71 plants with a daily capacity of 2,882,400 gallons natural gasoline and 1,155,500 gallons liquefied petroleum gases. Three new natural-gasoline plants were built in 1948, one each at Russell Ranch, Newhall-Potrero, and Cymric. The number of natural-gasoline and cycle plants in California has decreased from a maximum of 99 in 1941, and there is a trend toward fewer plants with larger capacities. The total number of natural-gasoline plants operating in the United States at the close of 1948 was 470, with a total daily productive capacity of more than 16,000,000 gallons. California ranked third in the number of such plants, following Texas and Oklahoma.

The largest-capacity natural-gasoline plants in California, and the number of gallons daily capacity, were as follows at the close of 1948:

Shell Company, Inc., at Ventura	140,000
General Petroleum Corporation, at Athens	130,000
Signal Oil Company, at Huntington Beach	130,000
Lomita Gasoline Company, at Wilmington	100,000
Standard Oil Company of California, at Murphy-Coyote	100,000

Largest-capacity liquefied petroleum gas plants were:

Standard Oil Company of California, at Kettleman Hills	180,000
Ohio Oil Company, at South Coles Levee	81,000
General Petroleum Corporation, at Athens	80,000
Western Gulf Oil Company, at Paloma	70,000

The two cycle condensate plants operating were:

Western Gulf Oil Company, at Paloma	252,000
Ohio Oil Company, at South Coles Levee	178,500

The distribution, by companies and number of plants, of the total of 74 operating natural-gasoline and cycle plants in California at the close of 1948 was:

Standard Oil Company of California	17
Union Oil Company of California	8
Shell Oil Company, Inc.	7
General Petroleum Corporation	6
Texas Company (California)	4
24 other operators of one to three plants each	32
Total	74

Distribution and Utilization. A very large part (approximately three-fourths) of the production of natural-gasoline plants goes to refineries. This amount includes most of the natural gasoline and natural-gasoline mixtures, condensate, normal butane, isobutane, isopentane, other liquefied petroleum gases, and finished gasoline and naphtha. More than half of the total natural-gas liquids shipped to refineries is natural gasoline. More natural gasoline and butane have been used in the manu-

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[1] Knudsen, E. T., Petroleum refineries, cracking plants, natural gasoline plants, and cycle plants in district five, January 1, 1949, 11 pp., Washington, U. S. Bur. Mines Petroleum Economics Branch, 1949.

*Production of natural gasoline and liquefied petroleum gases in California.**

Year	Thousands of barrels	Year	Thousands of barrels
1911-18	2,230	1935	12,962
1919	962	1936	14,569
1920	1,148	1937	15,274
1921	1,386	1938	16,438
1922	1,598	1939	15,251
1923	4,127	1940	15,122
1924	5,538	1941	15,501
1925	7,219	1942	15,130
1926	9,271	1943	16,508
1927	11,661	1944	18,367
1928	13,023	1945	21,175
1929	19,146	1946	19,745
1930	19,651	1947	25,336
1931	16,010	1948	26,477
1932	13,128		
1933	11,904	Cumulative total	391,336
1934	12,086		

* Figures prior to 1947 taken from Petroleum World Annual Review 1949, p. 205. Figures for 1947-48 supplied by U. S. Bur. Mines.

facture of automotive fuel in recent years; the blending of natural gasoline and refinery gasoline is accepted practice.

Jobbers and other trade outlets purchase roughly one-eighth of the natural-gas liquids. Their purchases are usually about two-thirds finished gasoline and naphtha, one-third natural gasoline, and a small percentage, condensate.

Liquefied petroleum gases are sold for fuel, chemical raw materials, and components of synthetic rubber. More than two-thirds of the butane is used for rubber; most of the balance for domestic and industrial fuel. Most of the propane is used in domestic and industrial fuel; some also in the manufacture of rubber. Butane, propane, and their mixtures constitute an important part of the manufactured gas sold.

Exports of natural gasoline and liquefied petroleum gases increased very rapidly after the war. The largest amounts are sent to the United Kingdom, Canada, and Mexico. Exports, compared to total demand, are not large, amounting to roughly three percent in 1946.

Production. Production of natural gasoline and liquefied petroleum gases in California increased rapidly from 1922 to 1930, dropped during the depression years, and began to rise again in 1935. The three years, 1946-48, show a strong trend upward which is expected to continue for some years to come. California production in 1948 was approximately 18 percent of the national total, and was exceeded only by Texas production, which was nearly half the national total.

Reserves. Texas has over half the natural-gas liquid reserves of the United States, followed in turn by Louisiana and California (California reserves are approximately one-tenth the national total). California reserves increased from a total of 308,272,000 barrels in late 1946 [2] to 312,151,000 barrels at the close of 1947 [3] and decreased during 1948 [3] to close at 307,908,000 barrels.

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[2] Estimate by committee on natural gas reserves of American Gas Association.

[3] Joint estimate of committees of American Petroleum Institute and American Gas Association.

Estimated proved recoverable reserves of natural-gas liquids in California, December 31, 1946, in thousands of barrels were:

	Nonassociated [1]	Associated [2]	Dissolved [3]	Total
California	40,328	107,300	160,644	308,272
Percent of total in United States	2	18	18	9

[1] Recoverable from free gas not in contact with crude oil in the reservoir.
[2] Recoverable from free gas in contact with crude oil in the reservoir.
[3] Recoverable from free gas in solution in crude oil in the reservoir.

*Production of natural gasoline and liquefied petroleum gases by counties.**

County	Natural gasoline		L. P. G.	
	Gallons	Value	Gallons	Value
Fresno [1]	26,623,000	$2,199,000	22,262,000	$1,400,000
Kern	143,654,000	11,865,000	107,801,000	6,781,000
Kings [1]	116,075,000	9,587,000	66,480,000	4,182,000
Los Angeles	313,871,000	25,923,000	19,982,000	1,257,000
Orange	115,378,000	9,529,000	9,785,000	615,000
Santa Barbara	24,987,000	2,064,000	8,419,000	530,000
Ventura	101,837,000	8,411,000	34,915,000	2,196,000
Totals	842,425,000	$69,578,000	269,644,000	$16,961,000

* Data supplied by Natural Gas, Gasoline Association, and adjusted to U. S. Bur. Mines totals.

[1] Natural-gas gasoline and compressed petroleum gases processed in Kettleman Hills oil field came from gas produced in both Kings and Fresno Counties. Such production is here assigned entirely to Kings County, because figures by county are not available.

PEAT

By Lewis T. Braun

During 1948 California produced 6,942 tons of peat, valued at $33,265. In addition, large quantities were imported to help meet the increasing demand for agricultural peat. The major California producers are at present initiating expansion programs as a result of this demand.

Geologic Occurrence. Peat is an accumulation of vegetal matter that has undergone decomposition and disintegration. It forms in lakes, swamps, and river deltas from mosses, tules, and grasses; a deficiency of oxygen prevents complete decay, and the carbonaceous matter is preserved. Tropical climate is not favorable to the formation of peat, because of the presence of bacteria that destroy the accumulating dead plant material.

Peat has formed in Recent geologic time, in the higher latitudes where climatic conditions were favorable. In California it is found chiefly in the deltas of the lower San Joaquin and Sacramento Rivers. Most of the state's peat output is from this region, but some deposits in Modoc, Orange, and San Diego Counties are also being worked.

The type of vegetation which accumulates determines the type of peat which is formed. The most valuable and sought-after commercial peat is formed from aquatic mosses. Most of this material is either a sphagnum or hypnum moss, and is known in the industry as "peat moss." From peat moss, commercial grades of peat range down through ordinary sedge or tule peat to ''peat dirt,'' which is a soil high in organic matter. The bulk of California's production is classified as peat or ''peat dirt.'' The only producer of high-grade peat moss in the western United States, however, is located in California.

Localities. The Modoc Peat Moss Company recovers a hypnum peat moss from a bog in Jess Valley, near Likely, Modoc County. At this locality peat moss is removed from the bog with a dragline, and is air dried. The drying takes from 1 week to 4 weeks. After drying, the material is either sold in bulk or is shredded and screened, and baled or packed in boxes. The value of this material, f.o.b. Likely, varies from $15 to $55 per ton. The last figure is for shredded and screened peat moss packed in 7-cubic-foot boxes. This product, ready for market, weighs about 270 pounds per cubic yard. Because of the high elevation (6,000 feet) and the rigorous winters, the bog cannot be worked all year. In 1949 about 16,000 cubic yards of peat moss were removed from the bog, and about 3,500 cubic yards were shipped. Because of an expanding market, the Modoc Peat Moss Company expects their 1950 shipments to equal their 1950 production.

A great deal of sedge grass or tule peat, and peat dirt is produced from the Sacramento and San Joaquin River deltas. The largest peat producer in the state is the California Peat Company of Antioch, California. The holdings of this company comprise a 2,600-acre submerged area which is near Bethel Island, and is known as Frank's Tract. The California Peat Company is removing sedge-grass peat from the bottom of this lake with a 1-cubic-yard dragline mounted on a barge. The depth of water varies from 6 to 8 feet. The wet peat is trucked about 10 miles to a drying ground near the west side of the Antioch bridge. Here the peat is sun-dried, and its density reduced from about 1,800 pounds per cubic yard to about 700 pounds per cubic yard.

After drying, the material is shredded. Future plans call for squeezing the bulk of the moisture out of the peat on the barge, and removing the remainder in a gas-fired kiln at the Antioch location. The deposit is known to be at least 17 feet thick, and the operators have made a tentative reserve estimate of 25 million cubic yards. At present, the California Peat Company is marketing about 2,500 cubic yards of peat per month, and they expect to expand their operations greatly during the next few years.

A small amount of the sedge-grass peat and ''peat dirt'' is being produced at several areas in the southern part of the state. In the Los Angeles area peat is being recovered from a bog near Huntington Beach. In San Diego County a recently drained lake bed was found to contain a good deposit of agricultural peat, but there was no production from this property during 1949.

Utilization and Markets. Ninety-five percent of the peat consumed in the United States is used as agricultural material; the remainder for miscellaneous purposes such as poultry-yard litter. Peat is not used as a fuel in the United States. This country has ample reserves of ordinary peat, but large quantities of peat moss are annually imported from Canada and the Netherlands. The bulk of this imported peat moss is used by nurseries for raising flowers and plants. Peat produced in California is either used directly as a soil conditioner, or is compounded with commercial fertilizers and then added to the soil.

PETROLEUM

By Gordon B. Oakeshott

The year 1948 was an outstanding one for the petroleum industry of California. Total production for the year, according to the United States Bureau of Mines, reached the all-time high of 340,089,000 barrels valued at $823,696,000, compared with a 1947 production of 333,132,000 barrels valued at $572,990,000. Reserves increased from 3,294,963,000 barrels on December 31, 1947, to 3,763,583,000 barrels on December 31, 1948, according to estimates of the American Petroleum Institute; this places California second to Texas among the states. The number of exploratory wells drilled in 1948 represented an increase of one-third over 1947, resulting in the most important discoveries in a decade. Discovery of the Russell Ranch oil field in Cuyama Valley and development in the San Ardo oil field in the Salinas Valley proved the existence of oil in commercial quantities in two new geologic provinces. The new discoveries and successful extensions of existing fields and pools added 207,000,000 barrels to reserves, the largest increase in several years. The price for crude oil reached the highest figure in history in late 1947 and remained unchanged during 1948.

Location of Oil Fields. California's oil fields are located in and around the margins of the principal Tertiary basins of southern California. The major oil fields are grouped in the Los Angeles Basin (northwest-trending fields of southern Los Angeles County); Santa Barbara-Ventura Basin (westward-trending fields of the Santa Barbara coast, from Capitan in Santa Barbara County, across Ventura County, to Placerita in western Los Angeles County); Santa Maria Basin (west-northwest-trending fields of northwestern Santa Barbara County); San Joaquin Valley (northwest-trending fields, from southwestern Kern County into southwestern Fresno County); Cuyama Valley Basin (northwest-trending Russell Ranch field, the first in this newly discovered petroleum-producing province); and Salinas Valley Basin (proved to be petroleum-producing by the San Ardo development).

The State Division of Oil and Gas publishes a series of maps of the oil and gas fields showing the location and status of wells drilled; maps of each of the five districts are also available.[1]

General Geology of Petroleum in California.[2] The accumulation of petroleum involves the formation of the hydrocarbons which constitute petroleum, the migration of the oil from source rocks into a reservoir rock, and a suitable structural or stratigraphic trap.

Petroleum is almost certainly of organic origin, forming by chemical-organic changes taking place in plant and animal materials deposited with accumulating sediments. All petroleum in California is found in reservoir rock closely associated with organic sediments which are mostly of Tertiary age. The repeated occurrence of oil-bearing sands in contact with or above diatomite and diatomaceous shale has been considered as evidence for the importance of the organic remains of diatoms

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[1] An outline map showing the location of district boundaries, and oil and gas fields, with an index to fields, may be found on pages 2 and 3 of Summary of Operations, California oil fields, California Div. Oil and Gas, July-Dec. 1948.

[2] An account of the geology of California and the occurrence of oil and gas, a geologic description of the individual fields, a glossary of geologic units, and bibliography to the close of 1941 may be found in Jenkins, O. P., and others, Geologic formations and economic development of the oil and gas fields of California: California Div. Mines Bull. 118, 1943.

*Summary of major geologic features of the oil fields.**

Field	Year of first production	Geologic formation of producing zones	Geologic age of producing formation	Structural controls
		DISTRICT 1 (LOS ANGELES AND ORANGE COUNTIES)		
Aliso Canyon	1938	Repetto formation, fractured Modelo shale, and Topanga sand	Lower Pliocene, upper Miocene, and middle Miocene	Steeply-dipping homoclinal beds
Brea-Olinda	1897	Several zones in Pliocene and Miocene formations	Pliocene and Miocene	Narrow faulted anticlines
Coyote, East	1911	Several zones in Repetto and Puente formations	Lower Pliocene and upper Miocene	Series of domes along a sinuous east-trending axis
Coyote, West	1909	Repetto formation	Lower Pliocene	East-trending anticline
Del Valle	1940	Modelo sand	Upper Miocene	Southeast-plunging anticline with fault closure on west
Dominguez	1923	Repetto and Puente formations	Lower Pliocene and upper Miocene	Elongated dome trending south-southeast; cross-faulted
El Segundo	1935	Schist conglomerate and Franciscan (?) schist	Miocene and Jurassic (?)	Domed sediments on Franciscan (?) schist high
Huntington Beach	1920	Repetto and upper Modelo formations	Lower Pliocene and upper Miocene	Pools in faulted homocline and anticlines; offshore
Inglewood	1924	Several zones in lower Pico, upper Repetto, near Pliocene-Miocene sand, Topanga sand	Pliocene; middle Miocene	Faulted dome, elongated northwest
Long Beach	1921	Many zones in Pico, Repetto, and Puente formations	Pliocene and upper Miocene	Northwest-trending, narrow faulted asymmetrical anticline
Los Angeles City	1892	Upper Puente sandstone	Upper Miocene	Minor zone of faulting and sharp folding on south-dipping beds

Montebello	1917	Repetto and Puente formations	Lower Pliocene and upper Miocene	East-trending elongated domes; east Montebello dome faulted on east
Newhall	1889	Various zones, chiefly Pliocene; uneconomic oil in Eocene and "schist"	Pliocene; Eocene; Paleozoic (?)	Several separate complex structures, including the Pico anticline
Newhall-Potrero	1937	Five zones	Upper Miocene	Narrow asymmetrical anticline, trending N. 60° W.; severely cross faulted
Newport, West	1943	Four zones in Puente sands	Upper Miocene	Northwest-plunging nose; much faulted
Oak Canyon	1941	Sand of Mohnian age	Upper Miocene	Faulted east-plunging anticline
Playa del Rey	1929	Lower Pliocene, basal Modelo schist conglomerate, and schist	Lower Pliocene, upper Miocene, and Jurassic (?)	Northwest-trending elongated dome of sediments deposited on schist high
Potrero	1928	Numerous zones in Pico and Repetto formations	Upper and lower Pliocene	Dome elongated N. 65° W.; gentle dips; cut into four blocks by faults
Richfield	1919	Three main zones in upper Puente formation	Upper Miocene	Several traps, including a closed anticline with east-trending arcuate axis
Rosecrans	1924	Repetto and upper Puente formations	Lower Pliocene and upper Miocene	Elongated dome; parallel faults and cross faults
Santa Fe Springs	1919	Eight major zones in Repetto and Puente formations	Lower Pliocene and upper Miocene	Dome, slightly elongated northwest
Seal Beach	1926	Repetto and Puente formations	Lower Pliocene and upper Miocene	Two elongated northwest-trending domes, cut by parallel faults on northeast limb
Torrance	1922	Repetto and Puente formations	Lower Pliocene and upper Miocene	Broad gentle anticline, axis striking N. 65° W.
Whittier	1898	Repetto and Puente formations	Lower Pliocene and upper Miocene	South-dipping homocline against Whittier fault
Wilmington	1935	Several zones in Repetto and Puente formations; schist conglomerate; Franciscan (?) schist	Lower Pliocene, upper Miocene; middle Miocene; Upper Jurassic (?)	Closed anticline trending west-northwest, divided into a series of blocks by cross faults

* Fields with fewer than an average of 10 producing wells during the second half of 1948 omitted.

*Summary of major geologic features of the oil fields *—Continued.*

Field	Year of first production	Geologic formation of producing zones	Geologic age of producing formation	Structural controls
		DISTRICT 2 (VENTURA COUNTY)		
Bardsdale	1894	Sespe formation and Eocene	Oligocene (?) and Eocene	Asymmetrical domes on Oakridge anticline
Ojai	1885	Sespe formation	Oligocene (?)	Complex; thrust faulting important
Piru	1887	Monterey formation	Miocene	Various anticlinal structures
Rincon	1927	Pico and Repetto formations	Pliocene	Complexly faulted narrow anticlines
Santa Paula	1875 (?)	Repetto formation and upper Modelo fractured shales	Lower Pliocene and upper Miocene	Steeply dipping homoclincal beds (?)
Sespe	1887	Tejon, Sespe, and Vaqueros formations	Upper Eocene, Oligocene (?) and lower Miocene	Topatopa anticline, most important; San Cayetano overthrust and tight synclines and anticlines
Simi	1900 (?)	Llajas and Sespe formations	Eocene and Oligocene (?)	Asymmetrical anticline, faulted along south side
South Mountain	1916	Sespe formation	Oligocene (?)	Dome on Oakridge anticline; cross faulted
Ventura	1916	Pico and Repetto formations	Pliocene	Slightly asymmetrical faulted anticline; axis traceable eastward 17 miles

*Summary of major geologic features of the oil fields *—Continued.*

Field	Year of first production	Geologic formation of producing zones	Geologic age of producing formation	Structural controls
DISTRICT 3 (COASTAL COUNTIES; PRINCIPALLY SANTA BARBARA, SAN LUIS OBISPO, AND MONTEREY)				
Arroyo Grande	1906	Sisquoc and Pismo (Santa Margarita) formations	Lower Pliocene to upper Miocene	North flank of Pismo syncline; tar seal
Capitan	1929	Vaqueros formation; several zones in Sespe formation; Gaviota-Sacate zone	Lower Miocene; Oligocene (?); Oligocene-Eocene	Anticlinal dome, closed on north by a normal fault dipping north
Casmalia	1904	Fractured cherty Monterey shale; Lospe formation	Upper Miocene; lower Miocene	Simple asymmetrical anticline
Cat Canyon	1907	Basal Foxen and Sisquoc formations; fractured Monterey shale	Upper and lower Pliocene; upper Miocene	Sand lenses on northwest-plunging anticlinal noses
Elwood	1928	Temblor fractured shale; Vaqueros and Sespe sands	Middle Miocene; lower Miocene and Oligocene (?)	West-northwest-trending closed anticline
Lompoc	1902	Some oil in basal Sisquoc, most in upper Monterey fractured shale	Upper Miocene	Two closed anticlines en echelon; faulted
Mesa	1929	Vaqueros	Lower Miocene	Faulted monocline
Orcutt	1902	Basal Sisquoc sand and fractured shale; Monterey sands	Upper and middle Miocene	Asymmetrical dome; faulted
Russell Ranch	1948	Dibblee and Colegrove sand zones	Lower Miocene	Narrow northwest-trending monocline with closure against normal Russell fault
San Ardo	1947	Lombardi and Campbell pools in Stevens sand	Upper Miocene	Pliocene stratigraphic trap
Santa Maria Valley	1934	Tar sand in Foxen; main production from fractured Monterey cherty shale	Pliocene (Foxen) upper and middle Miocene	North limb Santa Maria Valley syncline; sediments on irregular surface Franciscan (?) high
Zaca	1942	Fractured Monterey cherty shale	Upper Miocene	Southwest-dipping homocline in Monterey, overlapped by Sisquoc formation

*Summary of major geologic features of the oil fields *—Continued.*

Field	Year of first production	Geologic formation of producing zones	Geologic age of producing formation	Structural controls
		DISTRICT 4 (KERN COUNTY)		
Antelope Hills	1942	Middle Miocene sand	Middle Miocene	Open southeast-plunging syncline; oil sands truncated by alluvial beds
Ant Hill	1944	Olcese (Temblor) and Jewett (Vaqueros) zones	Middle and lower Miocene	Small faulted fold on south-dipping homocline
Belridge, North Belridge, South	1912 1911	Tulare	Pleistocene	Long, narrow, asymmetrical anticlines, en echelon
		Etchegoin	Lower Pliocene	
		Reef Ridge McLure Maricopa	Upper Miocene	
		Temblor	Middle Miocene	
		Kreyenhagen sand	Upper Eocene	
Blackwells Corner	1944	Santos sand (Temblor)	Middle Miocene	Faulted anticline
Canal	1937	Upper Stevens sand	Upper Miocene	Dome, with small closure, elongated eastward
Coles Levee, North	1938	Etchegoin, basal Stevens sand, and a lower Miocene sand	Lower Pliocene, upper Miocene, and lower Miocene	Faulted anticline
Coles Levee, South	1938	Stevens sand	Upper Miocene	
Cymric	1916	Tulare	Pleistocene	Structure obscure; possibly crenulations on McKittrick Hills anticline; overlaps
		Etchegoin	Lower Pliocene	
		Carneros	Middle Miocene	
		Phacoides	Lower Miocene	
		Oceanic	Oligocene-upper Eocene	
		Kreyenhagen	Upper Eocene	
		Point of Rocks	Upper Eocene	

Edison	1931	Upper Duff zone Chanac formation Oleese sand Fractured schist	Pleistocene-Pliocene Lower Pliocene-upper Miocene Middle Miocene Pre-Upper Jurassic	Complex structure Overlap, warp Westward tilt, faulting
Elk Hills	1919	Scalez zone (San Joaquin formation) Stevens sand Vedder sand	Upper Pliocene Upper Miocene Lower Miocene	Closed anticline, elongated three times its width; cross faulted 43,800 acres
Fruitvale	1928	Chanac and Santa Margarita formations	Lower Pliocene-upper Miocene	Low-relief dome on Kern River uplift; faulted
Greeley	1936	Stevens and Vedder sands	Upper Miocene and lower Miocene	Northwest-trending closed anticline; length four times its width
Kern Bluff	1947	Transition and Santa Margarita sands	Lower Pliocene-upper Miocene	Faulted anticline
Kern Front	1925	Zones in Chanac formation	Lower Pliocene-upper Miocene	Faulted homocline
Kern River	1899	Kern River formation	Pleistocene to lower Pliocene	Lenticular sands along gently dipping homocline
Lost Hills	1910	Zones in Etchegoin and Temblor sands	Lower Pliocene and middle Miocene	Long narrow closed anticline
McKittrick-Temblor	1887	Zones in Tulare, Etchegoin, and Vaqueros	Pleistocene-Pliocene, lower Pliocene, and lower Miocene	Crenulations on east-dipping homocline; local faults and unconformities
Midway-Sunset	1901	Many zones from Tulare to fractured Miocene shale	Pleistocene to middle Miocene	Anticlines of Buena Vista Hills; Pliocene-Miocene overlaps of North Midway; asymmetric Midway anticline; Spellacy anticline; Etchegoin overlapping Reef Ridge
Mt. Poso	1926	Vedder sand, Vaqueros formation	Lower Miocene	Faulted homocline
Mountain View	1933	Transition Wharton Chanac	Lower Pliocene to upper Miocene	Complex minor structures, including faults, on broad westward-dipping homocline
		Fractured schist	Pre-Upper Jurassic	
Paloma	1939	Stevens sand zones	Upper Miocene	Anticline; faulted

*Summary of major geologic features of the oil fields *—Continued.*

Field	Year of first production	Geologic formation of producing zones	Geologic age of producing formation	Structural controls
		DISTRICT 4 (KERN COUNTY) Continued		
Poso Creek	1929	Chanac and Santa Margarita formations	Lower Pliocene-upper Miocene	Faulted homocline
Rio Bravo	1937	Vedder and Rio Bravo sands (Vaqueros)	Lower Miocene	Northwest-trending dome; length twice its width
Round Mountain	1927	Elbe, Jewett, and Vedder zones of Vaqueros formation	Lower Miocene	Complexly faulted monocline
Strand	1939	Stevens sand	Upper Miocene	Anticline
Tejon	1937	Chanac formation and transition sands	Lower Pliocene-upper Miocene	Dome, anticlinal nose, and faulted homocline (separate structures)
Ten Section	1936	Upper and lower Stevens sand	Upper-Miocene	Closed anticline with an arcuate axis, eastward trend
Wheeler Ridge	1922	Santa Margarita and Maricopa formations	Upper Miocene	East-trending asymmetrical closed anticline
Comanche Point area. (Abandoned late 1948)	1947	Chanac-Santa Margarita formations; extremely shallow	Lower Pliocene-upper Miocene	Fault traps (?)
McDonald anticline area	1945	Button bed (Temblor) and Phacoides zone (Vaqueros)	Middle and lower Miocene	Anticline

*Summary of major geologic features of the oil fields *—Continued.*

Field	Year of first production	Geologic formation of producing zones	Geologic age of producing formation	Structural controls
		DISTRICT 5 (FRESNO AND KINGS COUNTIES)		
Coalinga	1887	Temblor, Hondo, and Moreno formations	Middle Miocene, Eocene, and Upper Cretaceous	Homocline and southeast-dipping asymmetrical anticline
East Coalinga Extension	1938	Gatchell sand of Domengine formation	Middle Eocene	Southeast-plunging anticlinal fold
Helm	1941	Chiefly Temblor; a little Eocene	Middle Miocene and Eocene	Dome of low relief; faulted
Jacalitos	1941	Temblor	Middle Miocene	Prominent anticline, southeast plunge; unconformity at top of oil sand; faulted
Kettleman North Dome	1928	Temblor, Vaqueros (?), and Avenal formations	Middle Miocene, lower Miocene, and middle Eocene	Northwest-trending elongated asymmetrical dome with more than 3,000 feet of closure
Pleasant Valley	1943	Gatchell sand of Domengine formation	Middle Eocene	Similar to East Coalinga Extension (?)
Pyramid Hills	1940	Sands	Lower Oligocene (?) or upper Eocene (?)	Overlap (?)
Raisin City	1941	Continental beds of Temblor formation	Middle Miocene	Southeast plunge on structure of low closure
Riverdale	1941	Temblor Domengine	Middle Miocene Middle Eocene	Anticlinal fold with moderate closure

as a source for much California oil. It is probable that a wide variety of organic matter has contributed to formation of the petroleum.

Because of the physical characteristics of oil, gas, and water, migration of petroleum usually takes place in an up-dip direction in more or less porous and permeable stratified rock. As such migration takes place the reservoir rock may become less permeable, under the influence of a stratigraphic or structural trap, and migration is slowed down or stopped to allow accumulation.

In the great majority of California's 120 or more fields, sandstone is the reservoir rock in which the oil is found in commercial quantities. The sandstone, however, has a wide range in coarseness, porosity, and permeability. In a few fields, at least one of the oil-producing horizons is as coarse as conglomerate; this is true of El Segundo, Playa del Rey, and Wilmington. About 5 percent of the fields, including Casmalia, Cat Canyon, Elwood, Lompoc, Orcutt, Santa Maria Valley, Zaca, Aliso Canyon, Santa Paula, and Midway-Sunset, produce all or part of their oil from fractured chert or shale. A few fields, including El Segundo, Playa del Rey, Wilmington, Edison, and Mountain View, get some production from pre-Cretaceous fractured crystalline rocks.

The age of the reservoir rock in California oil fields ranges from pre-Cretaceous to Pleistocene. Some fields produce from as many as five geologic epochs; only one-third of the fields produce solely from formations of one epoch. The greatest part of California production is now from formations of Miocene age.

Percentage of fields producing from formations of various ages

Pleistocene	5	Eocene	12
Pliocene	33	Cretaceous	1
Miocene	61	Pre-Cretaceous	5
Oligocene	7		
		Total	124 *

* Total percentage is over 100 because some fields produce from rocks of two or more ages.

Late Tertiary formations in most California oil fields have been intensely folded and faulted. Many of the sedimentary beds involved are lenticular and show rapid changes in texture and thickness. Unconformities are numerous. Traps, consequently, are complex and commonly combine structural and stratigraphic factors. Many structures originated far back in the Tertiary period but the most important diastrophic epoch in the oil-producing regions was probably the middle Pleistocene. Many of the traps were forming, therefore, and petroleum was migrating into them in middle and late Pleistocene time. The following structural and stratigraphic traps are most important in California: (1) asymmetrical faulted anticlines and domes; (2) anticlines and domes, with minor faulting; (3) faulted anticlinal noses; (4) faulted homoclines; (5) faulted monoclines; (6) thrust faults and normal fault blocks; (7) unconformities and overlaps; (8) domed structures over old topographic highs; (9) lensing, and changes in thickness and texture of sandstone beds; and (10) up-dip tar seals. The more simple and obvious structures have been tested; new discoveries may be expected in more complex, obscure, and buried structures and in stratigraphic traps.

New Fields, 1940-48.[3] The principal new field discoveries in California from 1940 to 1948 were as follows:

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[3] Including only those fields with an average of 10 or more producing wells in the second half of 1948.

1940
  Del Valle
  Pyramid Hills

1941
  Helm
  Jacalitos
  Oak Canyon
  Raisin City
  Riverdale

1942
  Antelope Hills
  Zaca

1943
  Newport, West
  Pleasant Valley

1944
  Ant Hill
  Blackwells Corner

1945
  McDonald Anticline

1946
  None

1947
  Comanche Point
    (abandoned 1948)
  Kern Bluff
  San Ardo

1948[4]
  Guijarral Hills
  Placerita
  Russell Ranch

Russell Ranch. First production in Cuyama Valley was obtained by the Norris Oil Company in 1948. The valley was thus opened as a new petroleum province. The Norris well proved production in a small isolated fault block and was yielding only 10 barrels per day at the close of the year. The Russell Ranch field was discovered by Richfield Oil Corporation in June 1948 when Russell 28-5 was brought in for 500 barrels per day of 38.5° gravity oil at a location 3¼ miles southeast of the Norris well. By the end of 1948 there were 43 wells in the field producing a total of 12,000 barrels per day.

The Russell Ranch field is about half a mile wide, and trends northwest for 4½ miles along the western side of Cuyama Valley, extending across the Cuyama River from Santa Barbara County into San Luis Obispo County; the larger part of the field is in Santa Barbara County.

Production comes chiefly from the Dibblee sand at a depth of about 3000 feet, but some oil is obtained from the Colegrove sand at a depth of about 4000 feet. Both sands are fine- to coarse-grained, highly porous and permeable, and capable of high yields; their age is lower Miocene. The geologic section is:

Recent	Alluvium
Pleistocene	Fanglomerate
Pliocene	Morales continental beds
Upper Miocene	Santa Margarita formation
Upper to middle Miocene	Monterey formation
Lower Miocene	Dibblee sand Soda Lake shale Colegrove sand
Cretaceous	

Structurally, the field is a narrow northwest-trending monocline with closure along the southwest limb against the pre-Pliocene Russell normal fault. Closure in the Colegrove zone is about 450 feet. The post-Pliocene Whiterock thrust fault, apparent at the surface, did not influence accumulation but obscured the subsurface structure.

Guijarral Hills. Barnsdall Oil Company Fred Smith 1, the discovery well in the Guijarral Hills field, was completed in September 1948 for 800 barrels per day of 37.8° gravity oil. The new field is in Fresno County about 2 miles southeast of the Pleasant Valley oil field. Produc-

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[4] Moody, Graham B., Developments in California in 1948: Amer. Assoc. Petroleum Geologists Bull., vol. 33, no. 6, June 1949.

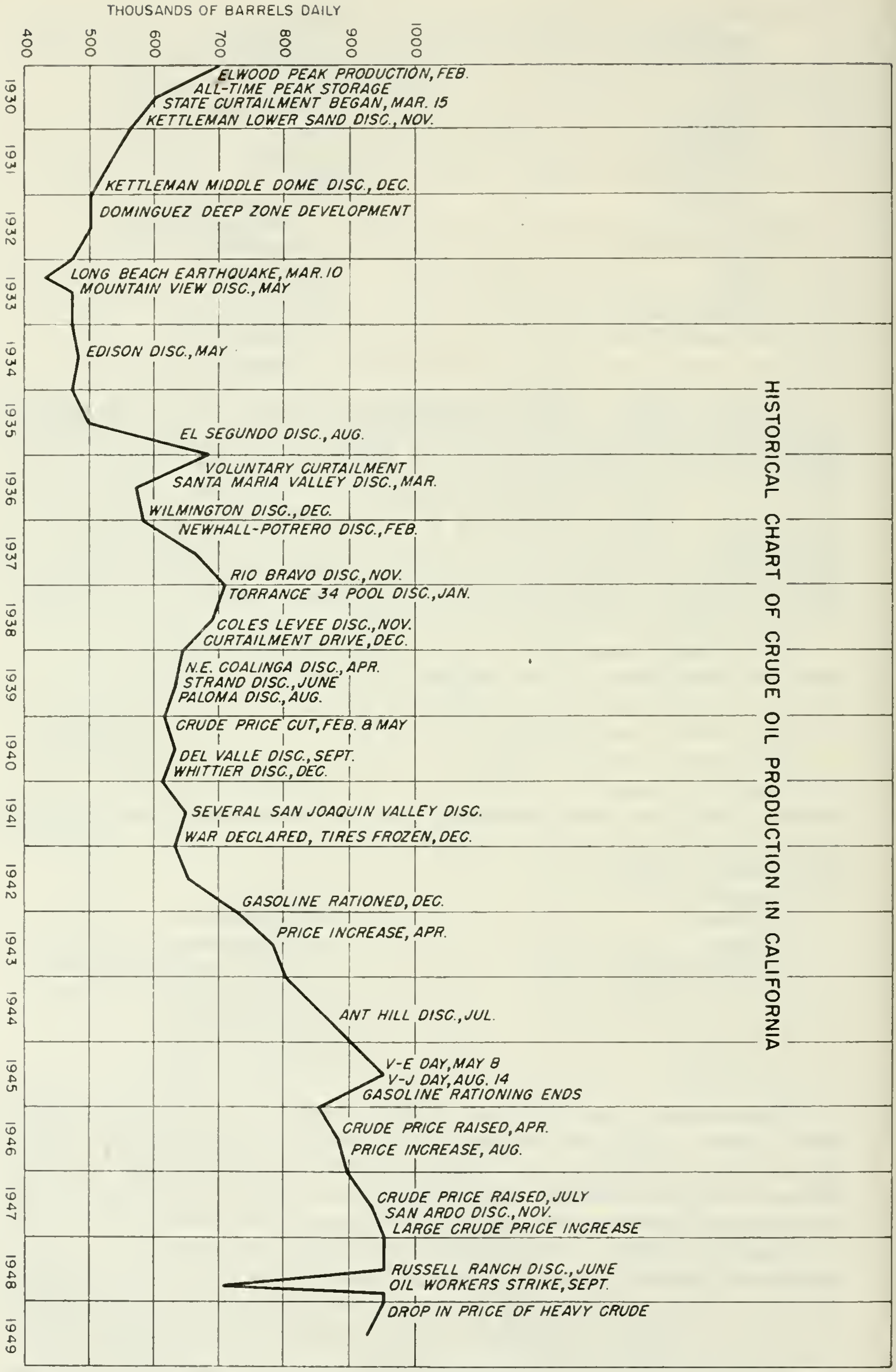

FIGURE 1. Chart showing crude oil production, 1930-49, and historical events that influenced production. A similar chart covering the years 1900-39 has been published in Division of Mines Bulletin 118, pl. 1.

tion is coming from the Oligocene Leda sand on a southeast extension of the Coalinga nose. Accumulation of oil has been caused by stratigraphic changes up-dip; limits of the sand body and extent of the field down-dip are not yet known.

Placerita. Nelson-Phillips Oil Company's Kraft 1 was the discovery well at the Placerita field at Sierra Highway 2 miles east of Newhall in western Los Angeles County. By the end of 1948, there were 20 completions, producing from a few to 100 barrels per day of 11° to 16° gravity oil from depths of 600 to 1600 feet. Actually, since 1920, a very small production has come from the same structure and horizon in the area less than a mile southwest of the new discovery.

The field is at the western end of the San Gabriel Mountains where Tertiary sediments dip northwestward off pre-Cretaceous crystalline rocks. Formations exposed in the general area include the crystalline rocks, the continental upper Miocene Mint Canyon formation, marine lower and middle Pliocene beds, marine to continental upper Pliocene beds of the Pico formation, and the continental lower Pleistocene Saugus formation. The oil in the upper Pliocene sands has been trapped by up-dip lensing and minor unconformities in a westward-plunging nose, and by minor folds and faults. The west-northwest-trending San Gabriel fault limits production on the north and northeast.

San Ardo. The Texas Company's Lombardi 1, completed in November 1947, was the discovery well for the San Ardo field in Salinas Valley. The discovery was important as it proved the existence of petroleum in commercial quantities in the Salinas Valley province, and stimulated further exploration in that area. The Campbell pool, 3½ miles southeast of Lombardi 1, was opened to oil production by Jergins Oil Company and North American Consolidated Oil Company Orradre 15-12 in late 1948; this well produced an initial 275 barrels per day of 12.5° gravity oil.

The Lombardi, Campbell, and Biaggi pools are producing from upper Miocene Stevens sands. Oil accumulated during Pliocene time in stratigraphic traps along the up-dip edge of the sands; later deformation during Pleistocene time developed structures unfavorable to oil accumulation in the San Ardo area.

The beginning of an oversupply of heavy crude near the end of 1948 has caused San Ardo oil to be largely shut-in.

Kern Bluff. Commercial production was proven at the Kern Bluff field, midway between Kern River and Ant Hill, by Oceanic Oil Company when its Needham-Bloemer 15 was completed in September 1947. The well produced 100 barrels per day of 15.4° gravity oil. Production is coming from uppermost Miocene Transition and Santa Margarita sands from depths around 800 to 1200 feet. The structural trap is a faulted anticline.

Markets. A general price increase of 50 cents per barrel took place in December 1947 to bring the price of 27° gravity Signal Hill crude to $2.45, an all-time high. This price remained unchanged during 1948.

Demands for petroleum products in early 1948 came close to exceeding ability of the industry to supply them, although crude production and refinery operations were greatly increased. The total amount and value of petroleum production in California was the greatest in history.

Near the end of the year a definite oversupply of heavy crude began to develop, becoming serious in early 1949. This condition may become

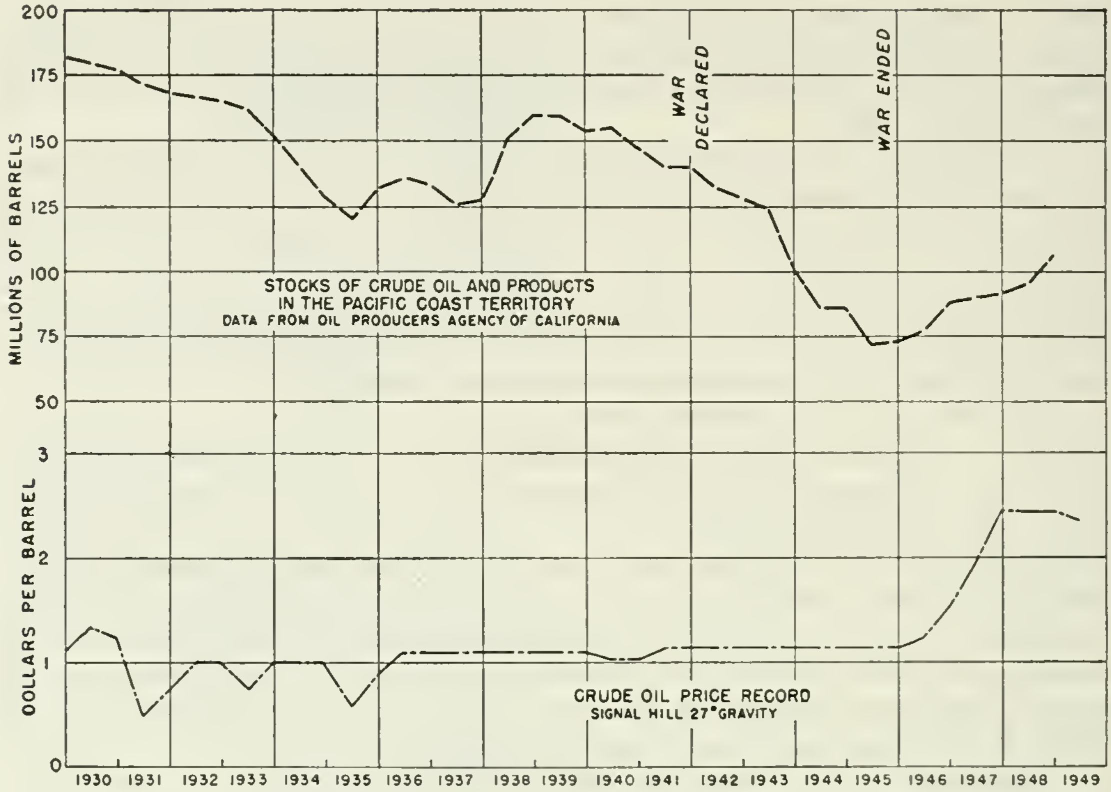

FIGURE 2. Chart showing crude oil price record, and stocks of crude oil and products in the Pacific Coast territory, 1930-48.

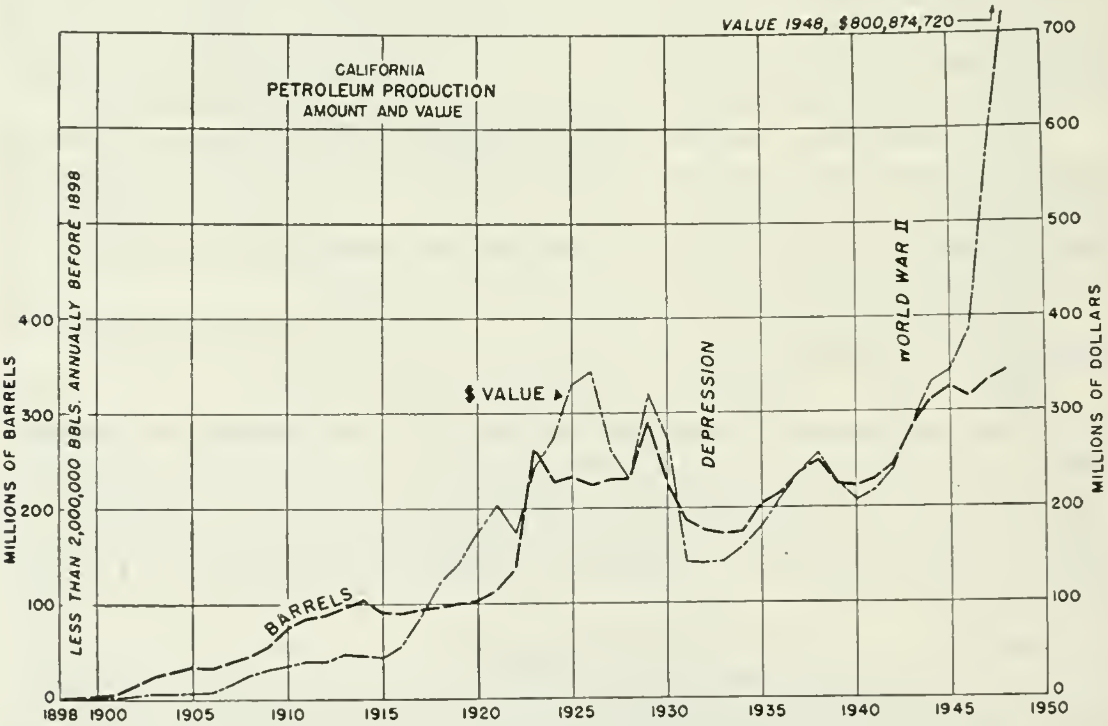

FIGURE 3. Chart showing amount and value of petroleum produced in California, 1898-1948.

of long-term importance, as it appears to be caused by a general decreasing demand for residual fuels, and by the increasing use of diesel oils and distillate fuels, natural gas, and gasoline.

The amount of petroleum imported into the United States in 1948 (estimated 184,000,000 barrels) exceeded total exports (estimated 135,000,000 barrels) but was not a large proportion of total production.

California demand exceeded one million barrels a day for several months, during a time when production was averaging about 929,000 barrels per day. If this trend continues, the California petroleum industry may begin a regular schedule of imports; however, this contingency seemed less probable at the close of the year.

*Petroleum production and value for 1948 by fields and counties.**

Fields	Approximate average gravity, degrees Baumé	Production in barrels	Value in dollars
Los Angeles County			
Aliso Canyon	28	1,226,234	3,004,273
Beverly Hills	17	34,243	73,280
Del Valle	36	2,044,653	3,250,998
Dominguez	30	4,860,666	12,443,305
El Segundo	21	141,762	312,491
Inglewood	23	4,376,332	10,153,090
Lawndale	28	250,492	618,715
Long Beach	25	8,132,892	19,356,283
Los Angeles City	15	77,556	162,868
Los Angeles East	35	412,848	1,114,690
Montebello	27	2,463,135	5,911,524
Newhall	19	94,481	209,748
Newhall-Potrero	35	2,726,371	7,061,301
Oak Canyon	32	719,485	1,813,102
Playa del Rey	22	699,312	1,559,466
Potrero	42	408,560	1,058,170
Rosecrans	33	1,567,606	4,075,776
Salt Lake	14	64,813	134,811
Santa Fe Springs	32	5,508,414	14,211,708
Seal Beach	26	4,151,812	10,254,976
Torrance	21	2,892,553	6,479,319
Turnbull	27	36,518	87,643
Whittier	22	364,839	839,130
Wilmington	22	48,320,459	111,620,260
Alondra area	25	283,799	658,414
East Dominguez area	30	7,452	19,077
Hyperion area	19	47,963	102,641
Leffingwell area	31	2,053	5,194
Puente area	22	2,257	4,965
Northwest Rosecrans area	33	137,659	357,913
Simi area	26	703	1,666
Whittier Heights area	23	3,890	8,558
Total		92,061,812	216,965,355
Deduction for Orange County		57,260	141,432
Total, Los Angeles County		92,004,552	216,823,923
Orange County			
Brea-Olinda	23	5,297,595	12,290,420
Coyote East	23	2,134,478	4,909,299
Coyote West	30	5,585,907	13,908,908
Huntington Beach	20	20,796,011	47,830,825
Newport	14	4,560	9,485
Newport, West	17	2,409,239	5,155,771

*Petroleum production and value for 1948 by fields and counties—Continued.**

Fields	Approximate average gravity, degrees Baumé	Production in barrels	Value in dollars
Buena Park area	24	13,545	31,831
Talbert area	18	6,194	13,565
Richfield area	20	2,293,226	5,090,962
Total		38,540,755	89,241,066
From Los Angeles County fields		57,260	141,432
Total, Orange County		38,598,015	89,382,498
San Bernardino County			
Chino Mahala area	23	1,982	4,559
Ventura County			
Bardsdale	27	660,083	1,597,401
Ojai	18	177,737	385,689
Oxnard	8	525,742	1,000,454
Piru	27	1,963,778	4,771,981
Rincon	30	5,081,762	12,399,499
Santa Paula	25	26,126	61,919
Sespe	21	73,301	163,491
Simi	26	58,257	139,816
South Mountain	23	2,424,791	5,577,019
Ventura	30	17,739,451	43,284,260
West Montalvo area	22	171,558	389,436
Total, Ventura County		28,902,586	69,800,965
San Luis Obispo County			
Arroyo Grande	17	45,045	92,792
Russell Ranch	34	6,816	17,653
Guadalupe area	18	7,630	15,794
Total		39,491	126,239
From Kern County fields		2,020	4,464
Russell Ranch (see Santa Barbara County)		402,871	1,043,435
Total, San Luis Obispo County		464,382	1,174,138
Monterey County		316	613
San Ardo	10	119,572	231,969
Total, Monterey County		119,888	232,582
Santa Barbara County			
Capitan	28	908,689	2,153,593
Casmalia	8	407,428	790,410
Cat Canyon	13	7,659,516	15,012,651
Elwood	34	2,681,359	6,944,719
Lompoc	19	2,318,666	4,822,825
Mesa	16	27,514	56,403
Orcutt	22	1,662,546	3,607,724
Russell Ranch	34	833,590	2,158,998
Santa Maria Valley	15	7,267,125	14,824,935
Summerland	18	4,204	9,122
Santa Barbara County, miscellaneous		13,544	26,548
Zaca area	8	611,847	1,186,983
		24,396,028	51,594,911
Deduction for Russell Ranch in San Luis Obispo County		402,871	1,043,435
Total, Santa Barbara County		23,993,157	50,551,476

*Petroleum production and value for 1948 by fields and counties—Continued.**

Fields	Approximate average gravity, degrees Baumé	Production in barrels	Value in dollars
Santa Clara County			
Moody Gulch	22	638	1,384
Sargent	17	-----	-----
San Benito County	14	1,251	2,477
Kern County			
Antelope Hills	17	440,552	973,620
Ant Hills	16	389,953	857,896
Belridge North	36	1,300,792	3,277,995
Belridge South	17	2,719,776	6,010,705
Blackwells Corner	13	49,957	108,406
Canal	37	634,969	1,625,520
Canfield Ranch	29	23,261	56,756
Coles Levee North	36	5,590,628	14,312,007
Coles Levee South	40	2,316,132	6,137,749
Cymric	14	9,167,619	19,985,409
Devils Den	19	14,876	33,173
Edison	18	4,836,731	10,737,542
Elk Hills	28	2,118,168	5,274,238
Fruitvale	20	2,510,580	5,623,699
Greeley	36	5,100,507	13,057,297
Kern Bluff	15	485,607	1,063,479
Kern Front	14	3,245,741	7,075,715
Kern River	13	4,513,544	9,794,390
Lost Hills	19	2,782,314	6,176,737
McKittrick-Temblor	16	1,442,520	3,173,544
Midway-Sunset	17	31,780,493	70,234,889
Mount Poso	26	4,569,050	10,554,505
Mountain View	15	1,305,584	2,859,228
Paloma	32–52	6,275,524	16,065,341
Poso Creek	13	1,290,504	2,800,393
Rio Bravo	40	4,431,482	11,787,742
Round Mountain	16	2,697,723	5,934,990
Strand	35	374,480	958,668
Tejon	18	1,132,576	2,514,318
Ten Section	38	2,379,332	6,233,849
Wasco	32	47,537	115,039
Wheeler Ridge	23	136,743	310,406
Bacon Hills area	36	91,727	234,821
Bellevue area	35	103,227	260,132
Chico-Martinez area	13	4,853	10,531
Comanche Point area	13	36,774	79,799
Jasmine area	15	64,577	141,423
Los Lobos area	15	793	1,736
McDonald Anticline area	15	69,181	151,506
McClung area	30	2,093	5,127
McKittrick area	-----	1,377	3,029
Total	-----	106,479,857	246,613,349
Deduction for San Luis Obispo County	-----	2,020	4,464
Total Kern County	-----	106,477,837	246,608,885

*Petroleum production and value for 1948 by fields and counties—Continued.**

Fields	Approximate average gravity, degrees Baumé	Production in barrels	Value in dollars
Fresno County			
Coalinga	15	9,319,358	20,409,394
East Coalinga Extension	23	22,940,676	52,075,334
Guijarral Hills		89,036	226,932
Helm	40	1,763,793	4,726,965
Jacalitos	40	2,140,512	5,736,572
Pleasant Valley	28	1,332,386	3,184,402
Pyramid Hills	40	84,851	227,400
Raisin City	24	1,099,562	2,507,001
Riverdale	35	1,154,995	2,922,137
Burrell area	26	21,795	50,782
Cantua Creek area	30	503	1,227
Cheney Ranch area	30	2,087	5,092
San Joaquin area	30	83,358	203,393
Total		40,032,912	92,277,631
From Kings County		6,265,697	16,541,440
Total, Fresno County		46,298,609	108,819,071
Kings County			
Kettleman Hills, Middle Dome	50	49,883	131,691
Kettleman Hills, North Dome	38	12,832,262	33,877,171
Total		12,882,145	34,008,862
Deduction for Fresno County		6,265,697	16,541,440
Total, Kings County		6,616,448	17,467,422
Sonoma County			
Petaluma	24	2,363	5,340
TOTAL, CALIFORNIA		343,481,708	800,874,720

* Data collected by California State Division of Oil and Gas.

Production statistics and operating data of California oil fields, 1948.‡

Field	January 1 to June 30				July 1 to December 31				Cumulative production of oil (bbls.) to end 1948	Proved acreage as of Dec. 31, 1948
	Average number of producing wells—actual	Oil (bbls.)	Production per well per day (bbls.)	Percentage of time wells produced	Average number of producing wells—actual	Oil (bbls.)	Production per well per day (bbls.)	Percentage of time wells produced		
DIST. 1—Aliso Canyon	37	644,493	108.6	88.2	41	581,741	96.6	79.8	8,975,729	765
Beverly Hills	2	17,809	49.5	98.9	2	16,434	46.0	97.0	4,042,890	15
Brea-Olinda	392	2,587,766	37.8	95.9	413	2,709,829	38.5	92.7	198,892,444	1,533
Coyote, East	205	1,075,290	29.8	96.6	215	1,059,188	28.6	93.7	59,874,923	1,185
Coyote, West	238	2,805,987	67.4	96.1	264	2,779,920	59.6	96.0	160,036,683	1,013
Del Valle	71	1,008,535	81.4	95.8	75	1,036,118	78.0	96.3	11,853,690	690
Dominguez	337	2,531,568	42.7	96.7	342	2,329,098	40.6	91.1	178,529,262	1,225
El Segundo	27	75,056	16.4	92.9	26	66,706	15.1	92.3	12,052,814	330
Huntington Beach	1,057	10,175,208	55.2	95.9	1,121	10,620,803	53.9	95.5	†416,908,915	3,465
Inglewood	317	2,052,811	37.3	95.3	341	2,323,521	39.7	93.3	165,501,400	945
Lawndale	5	66,165	86.6	84.0	11	184,327	109.3	83.3	1,417,722	90
Long Beach	1,112	4,234,270	21.7	96.5	1,111	3,898,622	20.9	91.1	†732,279,093	1,158
Los Angeles City	87	39,019	2.6	95.9	88	38,537	2.5	95.7	20,208,366	250
Los Angeles, East	8	230,461	169.0	93.7	8	182,387	136.8	90.6	994,817	150
Montebello	325	1,256,200	21.9	96.8	326	1,206,935	21.0	95.8	150,902,697	1,373
Newhall	19	21,516	7.8	79.4	32	72,965	15.1	82.0	6,096,723	505
Newhall-Potrero	56	1,273,397	138.1	90.5	64	1,452,974	134.5	91.7	16,701,166	840
Newport	1	1,737	12.1	79.1	2	2,823	15.3	50.0	163,815	30
Newport, West	175	1,155,257	38.6	94.0	189	1,253,982	37.3	96.5	†7,243,553	890
*Newport, West(gas)	0				0					
Oak Canyon	19	364,325	116.7	90.3	19	355,160	103.2	98.4	3,634,188	270
Playa del Rey	119	355,183	17.2	95.6	118	344,129	16.4	96.6	52,114,528	475
Potrero	27	208,475	43.8	96.8	29	200,085	41.5	90.3	6,617,879	230
Richfield	328	1,156,850	20.3	95.2	332	1,136,376	19.6	94.9	112,846,025	1,270
Rosecrans	183	798,640	25.1	95.7	188	768,966	23.5	94.5	62,852,012	785
Salt Lake	5	28,443	32.4	96.5	6	36,370	34.0	96.9	43,062,039	15
Santa Fe Springs	544	2,829,818	29.8	96.0	538	2,678,596	28.8	94.0	†523,342,133	1,010
Seal Beach	186	2,090,309	66.0	93.5	195	2,061,503	63.8	90.1	113,759,361	615
Torrance	738	1,455,093	11.2	96.4	742	1,437,460	10.9	96.3	†124,322,494	4,660
Turnbull	5	18,421	20.3	100.0	5	18,097	20.0	98.6	508,099	65
Whittier	159	187,294	6.8	95.1	163	177,515	6.2	95.4	21,686,538	610
Wilmington	1,936	24,752,350	72.3	97.1	2,007	23,568,109	67.1	95.1	417,772,120	5,455
Los Angeles County:										
Alondra area	5	156,234	182.7	94.0	5	127,565	138.7	100.0	686,794	50
East Dominguez area	1	4,249	25.0	92.4	1	3,203	22.1	78.8	26,270	10
Hyperion area	3	21,578	51.9	76.2	4	26,385	41.2	87.0	107,616	40
Leffingwell area	1	768	9.8	42.9	1	1,285	7.1	98.4	17,280	10
Puente area	1	735	32.0	12.6	1	1,522	8.3	100.0	†2,162	10
Northwest Rosecrans area	3	46,493	94.1	90.5	7	91,166	89.5	79.1	186,893	95
Simi area	0	0	0.0	0.0	1	703	6.3	60.9	2,087	10
Whittier Heights area	2	2,108	7.0	82.4	2	1,782	5.9	82.3	24,216	20

Production statistics and operating data of California oil fields, 1948 ‡—*Continued.*

Field	January 1 to June 30				July 1 to December 31				Cumulative production of oil (bbls.) to end 1948	Proved acreage as of Dec. 31, 1948
	Average number of producing wells—actual	Oil (bbls.)	Production per well per day (bbls.)	Percentage of time wells produced	Average number of producing wells—actual	Oil (bbls.)	Production per well per day (bbls.)	Percentage of time wells produced		
Orange County:										
Buena Park area	2	7,389	22.2	91.2	2	6,156	18.6	89.9	217,992	20
Talbert area	2	3,715	44.1	72.3	1	2,479	14.9	90.2	17,499	10
San Bernardino County:										
Chino-Mahala area	1	1,700	22.1	42.3	1	282	2.3	66.3	†19,489	10
Totals	8,741	65,742,715	43.0	96.0	9,039	64,861,834	41.4	91.1	3,636,502,416	32,217
Imperial carbon-dioxide gas	14	0	0	0	16	0	0	0	0	250
DIST. 2—Bardsdale	192	299,556	9.08	95.0	206	360,527	11.3	84.1	17,976,243	1,050
Ojai	59	89,362	10.8	76.7	51	88,375	14.0	67.5	3,615,092	670
Oxnard	7	283,466	254.2	87.5	8	242,276	197.1	83.5	2,933,770	230
Piru	140	965,194	42.4	89.4	154	998,581	39.6	89.1	13,930,929	800
Rincon	205	2,496,317	73.4	91.2	211	2,585,445	80.3	82.9	49,739,232	1,595
Santa Paula	30	12,704	3.2	72.2	34	13,422	2.8	77.7	2,342,523	195
Sespe	27	39,449	10.8	74.4	28	33,852	8.5	77.6	3,522,074	230
Simi	57	27,357	2.7	96.3	59	30,900	3.0	95.9	2,377,411	570
South Mountain	165	1,167,798	40.6	95.7	178	1,256,993	43.4	88.4	30,801,278	1,345
Ventura	594	9,350,594	99.7	86.7	596	8,388,857	99.2	77.1	355,408,034	2,635
West Montalvo	2	53,750	137.8	100.0	4	117,808	167.8	95.4	208,919	230
Totals	1,478	14,785,547	61.6	89.2	1,529	14,117,039	61.3	81.9	482,855,505	9,550
DIST. 3—Arroyo Grande	20	23,493	7.9	81.4	22	21,552	6.4	83.0	1,492,184	310
Capitan	64	496,457	44.6	95.5	66	412,232	36.8	92.2	12,815,474	230
Casmalia	27	185,118	51.2	73.5	39	222,310	39.6	78.3	15,869,983	1,040
Cat Canyon	190	3,679,674	121.3	87.7	224	3,979,842	110.4	87.5	56,945,273	3,090
Elwood	74	1,317,198	106.3	92.0	78	1,364,161	100.6	94.5	82,935,111	690
La Goleta gas	*9				*9	0			283	310
Lompoc	82	1,141,899	79.4	96.4	95	1,176,767	75.6	89.0	16,924,539	1,960
Mesa	16	13,498	5.7	81.1	17	14,016	5.3	84.8	3,607,411	22
Moody Gulch	1	445	14.8	16.5	1	193	24.1	4.0	62,039	10
Orcutt	231	872,530	21.6	96.0	239	790,016	21.3	84.3	107,488,016	3,550
Russell Ranch	1	20,624	97.3	100.0	21	819,782	302.6	68.0	840,406	270
San Ardo	1	3,569	23.3	84.1	13	116,003	74.3	65.3	120,309	440
Santa Maria Valley	478	3,849,737	46.7	94.7	481	3,417,388	41.6	92.9	91,564,068	6,260
Summerland	2	1,324	4.9	74.7	3	2,880	6.3	82.6	3,186,273	30
Zaca	6	201,629	221.3	83.4	10	410,218	276.8	80.5	973,620	250

Monterey County					1	316	22.6	7.6	316	0
San Benito County					1	1,251	8.0	85.3	1,251	0
San Luis Obispo County:										
Guadalupe area	1	1,154	38.5	16.5	2	6,476	29.2	60.3	7,630	30
Huasna area					0	0			0	
Santa Barbara County					3	6,877	16.3	76.6	20,037	30
Miscellaneous areas	3	6,667	14.9	82.1	0					0
Refugio area	*1				*1					10
Totals	1,197	11,815,016	58.5	92.9	1,316	12,762,280	59.6	88.5	394,854,223	18,532
Dist. 4—Antelope Hills	27	225,426	55.7	82.3	28	215,126	57.1	73.1	3,725,552	255
Ant Hill	32	206,902	35.8	99.2	32	183,051	31.1	99.1	1,658,338	295
Belridge, North	76	691,561	56.9	87.8	69	609,231	51.2	88.5	56,256,192	1,875
Belridge, South	561	1,215,071	12.8	93.3	668	1,504,705	13.1	93.1	45,774,715	6,205
Blackwells Corner	27	25,078	5.3	95.9	26	24,879	5.3	97.6	293,476	190
Canal	32	360,768	72.8	85.1	30	274,201	75.2	66.1	13,866,614	780
Canfield Ranch	3	9,378	19.6	87.7	3	13,883	27.9	90.0	277,125	60
Coles Levee, North	95	2,942,826	180.1	94.5	103	2,647,802	172.3	81.1	43,072,126	3,310
Coles Levee, North	*1				*1					
Coles Levee, South	63	1,290,726	130.0	86.6	60	1,025,406	132.8	70.0	14,956,612	3,200
Coles Levee, South	*3				*3					
Cymric	360	5,010,845	82.1	93.1	383	4,156,774	63.5	92.9	29,328,935	2,415
Devils Den	7	7,310	8.5	67.7	8	7,566	7.6	68.1	137,952	110
Edison	302	2,356,079	47.9	89.4	317	2,480,652	47.1	90.3	29,573,461	2,870
Elk Hills	149	1,177,174	66.6	65.2	149	940,994	54.1	63.4	198,445,660	16,660
Elk Hills	*3				*3					
Fruitvale	187	1,232,196	40.4	89.7	191	1,278,384	40.0	90.9	†44,006,511	2,055
Greeley	94	2,544,436	168.1	88.4	95	2,556,071	169.5	86.3	37,462,662	1,960
Kern Bluff	18	125,179	41.8	85.2	52	360,428	42.6	88.5	501,397	350
Kern Front	657	1,670,500	14.4	96.8	674	1,575,241	13.4	95.1	†68,957,249	4,220
Kern River	2,477	2,218,675	5.0	96.8	2,608	2,294,869	5.2	91.8	†300,390,637	8,035
Lost Hills	557	1,319,854	13.6	95.5	594	1,462,460	14.2	94.0	62,570,197	3,110
McKittrick-Temblor	248	729,375	16.5	97.8	249	713,145	16.9	92.2	96,514,899	1,350
Midway-Sunset	3,811	16,086,826	24.4	95.0	3,875	15,693,667	23.5	93.7	†1,098,011,698	[1] 43,220
Midway-Sunset	*22				*19					
Mount Poso	526	2,369,316	25.5	97.0	536	2,199,734	23.4	95.5	101,249,163	3,075
Mountain View	151	698,938	27.1	92.9	159	612,646	23.0	91.2	50,530,424	1,990
Paloma	90	3,101,719	198.5	95.4	100	3,173,805	181.4	95.0	19,475,784	6,230
Paloma	*1				*0					
Poso Creek	226	654,024	16.6	95.6	230	636,480	16.1	93.4	13,373,367	2,015
Rio Bravo	91	2,210,958	139.2	95.9	93	2,220,524	133.7	97.0	47,319,224	1,870
Round Mountain	354	1,399,440	22.4	97.0	359	1,298,283	21.1	93.0	55,873,371	2,390
Strand	22	229,209	61.6	92.9	20	145,271	50.5	78.2	5,869,868	380
Tejon	81	606,147	41.7	98.6	85	526,429	36.8	91.6	3,131,902	1,000
Ten Section	112	1,303,409	75.9	84.2	102	1,075,923	72.3	79.3	44,111,167	1,880
Wasco	4	26,663	40.9	89.6	4	20,874	38.8	73.1	4,689,605	150
Wheeler Ridge	35	45,786	7.4	96.5	44	90,957	12.2	91.9	4,612,434	360

Production statistics and operating data of California oil fields, 1948 ‡—Continued.

Field	January 1 to June 30				July 1 to December 31				Cumulative production of oil (bbls.) to end 1948	Proved acreage as of Dec. 31, 1948
	Average number of producing wells—actual	Oil (bbls.)	Production per well per day (bbls.)	Percentage of time wells produced	Average number of producing wells—actual	Oil (bbls.)	Production per well per day (bbls.)	Percentage of time wells produced		
DIST. 4—Antelope Hills—Continued:										
Kern County:										
Ant Hill area					1	587	6.2	51.1	587	10
Bacon Hills area	3	67,148	131.9	93.2	3	24,579	55.2	80.6	122,443	50
Bellevue area	3	54,771	107.4	93.4	3	48,456	91.3	96.2	702,084	60
Chico-Martinez area	4	3,038	7.6	55.1	3	1,815	7.9	41.7	54,432	30
Comanche Point area	6	7,340	7.5	89.7	13	29,434	13.8	89.4	37,839	85
Jasmine area	6	34,921	37.4	85.5	7	29,656	26.2	88.0	123,547	70
Los Lobos area	1	200	7.4	14.8	1	593	7.1	45.1	793	10
McClung area	1	1,282	10.9	64.8	1	811	33.8	13.0	105,867	10
McDonald Anticline area	11	20,892	11.4	91.6	17	48,289	15.8	97.9	115,324	120
McKittrick area					1	790	10.7	40.2	790	0
Bowerbank gas	*3				*3					1,360
Buttonwillow gas	*3				*2					410
Semitropic gas	*6				*5					1,600
Trico gas	*47				*70					[2] 10,008
Totals	11,510	54,275,386	27.4	94.6	11,996	52,204,471	25.7	92.2	2,497,315,323	137,778
Coalinga	*2									
DIST. 5—Coalinga	1,504	4,645,518	17.6	96.5	1,566	4,673,840	17.5	92.6	431,502,749	16,762
East Coalinga Extension	188	11,302,019	344.6	95.8	181	11,638,657	366.2	95.4	163,897,904	4,320
Guijarral Hills					2	89,036	241.9	46.7	89,036	220
Helm	82	955,996	66.9	95.8	81	807,797	58.6	92.7	8,620,817	4,230
Jacalitos	83	1,002,222	66.1	94.5	95	1,140,290	73.1	89.2	9,174,521	2,350
Jacalitos	*0				*0	0				
Kettleman Middle Dome	1	28,875	165.9	95.6	1	21,008	114.2	100.0	604,038	20
Kettleman North Dome	314	6,475,498	119.1	95.1	316	6,356,764	114.6	95.4	350,490,981	13,075
Pleasant Valley	22	646,982	176.0	91.8	22	685,404	176.3	96.0	6,617,192	490
Pyramid Hills	24	42,890	10.7	92.1	24	41,961	9.7	97.7	499,410	145
Raisin City	38	533,744	83.7	92.2	44	565,818	79.6	87.8	5,887,356	1,025
Riverdale	49	609,285	76.3	89.5	47	545,710	68.0	92.8	7,949,143	1,260
Fresno County:										
Burrel area	1	2,471	16.8	80.8	1	19,324	184.0	57.1	57,099	10
Cantua Creek area	1	503	11.2	24.7	0	0	0	0	3,649	10
Cheney Ranch area	1	1,069	6.2	95.1	1	1,018	5.6	98.4	8,869	10
San Joaquin area	3	39,694	76.3	95.2	3	43,664	81.3	97.3	147,640	60
Sonoma County:										
Petaluma area	1	1,032	15.6	36.3	1	1,331	7.2	100.0	5,667	50
Petaluma area	*0				*0					
Afton gas	*12				*2					40
Cache Slough gas	*2				*2					300
Eureka gas	*4				*4					400

Fairfield Knolls gas	*1				*1					240
Gill Ranch gas	*5				*5					810
Kirby Hill gas	*7				*8					730
Lodi gas	*4				*4					1,450
Maine Prairie gas	*7				*7					850
Marysville Buttes gas	*6				*6					840
McDonald Island gas	*5				*4					1,060
Millar gas	*3				*3					160
Ord Bend gas	*3				*3					210
Rio Vista gas	*131				*131					[3] 21,770
Roberts Island gas	*1				*1					20
Suisun Bay gas	*3				*3					60
Thornton gas	*9				*8					4,960
Tracy gas	*2				*1					175
Vernalis gas	*2				*2					100
Willows gas	*0				*0					20
Butte County:										
Chico area	*1				*1					20
Durham area	*1				*0					80
Colusa County:										
Colusa area	*0									0
Kings County:										
Trico Northwest area	*1				*1					20
Madera County:										
Chowchilla area	*0				*0					80
Moffatt Ranch area	*1				*1					20
San Joaquin County:										
Galt area	*1				*1					20
Solano County:										
Denverton area					*1					40
Honker area	*1				*0					20
Winters area	*0				*0					296
Tehama County:										
Corning area	*0				*0					120
Yolo County:										
Dunnigan Hills area	*0				*0					780
Pleasanton Creek area					*0					40
Winters area	*0				*1					124
Totals	2,312	26,285,798	65.2	95.9	2,385	26,631,622	65.3	93.0	985,556,071	79,892
Grand totals	25,238	172,904,462			26,265	170,577,246			7,997,083,538	277,969
Abandoned fields									1,267,774	
STATE TOTAL									7,998,351,312	

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‡ Data from Summary of Operations, California oil fields, Div. Oil and Gas, July-Dec. 1948.
* Dry gas wells omitted from well totals.
† Corrected figure due to receipt of amended production reports.

[1] Includes 65 acres in San Luis Obispo County, District No. 3.
[2] Includes 1,000 acres in Kings County, District No. 5.
[3] Includes 953 acres in Contra Costa County, District No. 3.

Abandoned fields or areas.

	Cumulative production of oil (bbl.)		Proved acreage, maximum
DIST. 1—Los Angeles County:			
Lapworth area	54,829		10
La Mirada area	20,571		10
Ramona area	1,606		10
Rowland area	1,885		10
DIST. 2—Ventura County: Conejo field	102,000		95
DIST. 3—Santa Barbara County: Goleta field	140,281		50
Santa Clara County: Sargent field	783,759		80
San Luis Obispo County: Huasna area	11,470		10
San Mateo County: Half Moon Bay area	41,330		40
DIST. 4—Kern County:			
Comanche area	55		0
Dyer Creek area	27,755		10
Northeast of Edison field	695		0
Grapevine area	3,871		0
Shafter area	54,651		60
Tulare County: Terra Bella area	23,016		40
Totals	1,267,774		425

PART III

NONMETALLIC INDUSTRIAL MATERIALS

CONTENTS

ABRASIVES

By Lewis T. Braun

During the past few decades the industrial use of abrasives has greatly increased. Most major industries use one or more types of abrasive material, and abrasive production closely parallels industrial activity. At present, sand, pumice, and pumicite are the only abrasives produced in quantity in California, but other raw materials from California sources can also be used for many natural or manufactured abrasives. The following list classifies the principal abrasives in use today:

I. Natural abrasives
  (1) High-grade natural abrasives
    (a) Diamond
    (b) Corundum
    (c) Garnet
  (2) Siliceous natural abrasives
    (a) Sandstone and sand
    (b) Quartz and quartzite
    (c) Grinding pebbles
    (d) Diatomite
    (e) Tripoli
    (f) Feldspar
    (g) Kaolin
    (h) Talc
    (i) Pumice and pumicite
II. Artificial abrasives
  (1) Silicon carbide
  (2) Crystalline oxide of aluminum
  (3) Boron carbide

NATURAL ABRASIVES

Diamond. Since the early days of gold mining in California, diamonds have occasionally been found in gold placers of the Sierran foothill counties and Siskiyou and Trinity Counties. The placers of the Cherokee district, Butte County,[1] which have yielded more than 300 diamonds of good quality, have been the principal source. Primary diamond deposits in the Cherokee district have not been found, and none of the placer deposits of the state can be considered a potentially commercial source of abrasive diamonds. All of the world's known primary occurrences of diamonds are in pipes of serpentinized ultrabasic rocks. Such rocks were undoubtedly the source of California's placer diamonds.

Corundum. Occurrences of corundum (Al_2O_3) are uncommon in California, and those that are known have not been considered commercially exploitable. Fourteen corundum localities, widely scattered throughout the state, have been listed by Murdoch and Webb.[2]

Though corundum deposits in the Appalachian belt of the eastern United States have been operated in the past, all corundum for domestic consumption is now imported, principally from the Union of South Africa. Commercial deposits of corundum are ordinarily in bodies of silica-poor igneous rocks, but most of the California occurrences are in metamorphic rocks.

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[1] Eakle, A. S., Minerals of California: California Div. Mines Bull. 91, pp. 7-8, 1922.

[2] Murdoch, Joseph, and Webb, R. W., Minerals of California: California Div. Mines Bull. 136, p. 122, 1948.

Garnet. Garnet, an important natural abrasive, occurs at many localities throughout California, but has not been mined in quantity. Garnet is a constituent of many metamorphic rocks, and of some igneous rocks, but commercial deposits of abrasive garnet are invariably of metamorphic origin. To be of economic interest such deposits must be of relatively large tonnage, and contain an average of more than 10 percent recoverable garnet in grains three-sixteenths of an inch in diameter or larger.[3]

There are six main subspecies of the mineral garnet. These have the same crystal habit and the same general formula, but are composed of different combinations of the silicates of magnesium, aluminum, iron, calcium, manganese, and chromium. Of the three most common types, grossularite ($Ca_3Al_2(SiO_4)_3$) occurs chiefly in crystalline limestone as the product of contact or regional metamorphism. Andradite ($Ca_3Fe_2(SiO_4)_3$) and almandite ($Fe_3Al_2(SiO_4)_3$) occur in schists and gneisses as products of regional metamorphism.

The production of garnet in California is currently confined to a single source. Since 1938, Huntley Industrial Minerals, Inc., have annually produced small amounts of abrasive garnet (principally grossularite) from tungsten mill tailings. The garnet is a constituent of the tungsten-bearing rock of the Pine Creek district, Inyo County.[4]

The garnet, after concentration, is marketed as blast sand which has been used principally by the aircraft industry.

An andradite garnet deposit[5] northwest of Cadiz Station, San Bernardino County, was prospected in 1931-32 by Pacific Coast Garnet Company, but the property has since been idle. A few tons of garnet rock were mined at the Sunny Day mine near Indio, Riverside County, in 1936-37, but were not shipped.[5]

Virtually the entire world production of abrasive garnet comes from two localities in New York State, and one in New Hampshire. At each of these, almandite garnet is produced from schist and gneiss.[5] The average ore contains from 10 to 15 percent garnet, and some contains as much as 60 percent garnet.

About nine-tenths of the abrasive garnet produced in the United States is used in the manufacture of abrasive papers and cloths. The remaining one-tenth is used principally as loose grains for polishing and blasting. Garnet abrasive paper and cloth are consumed largely by the manufacturing industries in the finishing of wood, leather, hard rubber, celluloid, felt and silk hats, painted and varnished surfaces, and for other miscellaneous uses. Garnet abrasives play an important part in the fabricating industries; but, because of the competition from manufactured abrasives, the demand for garnet has declined steadily since 1923.

In January 1950, the New York price for Adirondack garnet grain concentrates was $85.00 per ton,[6] but the by-product garnet from the California tungsten tailings has been valued between $16 and $18 per ton.

Sand, Sandstone, and Crushed Rock. In 1938, approximately 100,000 tons of sand, sandstone, and crushed rock were marketed in California for abrasive purposes. This was consumed mostly as sand-

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[3] Eardley-Wilmot, V. L., Abrasives, in Industrial minerals and rocks, p. 30, Am. Inst. Min. Met. Eng., 1937.

[4] See section on tungsten in this bulletin.

[5] Eardley-Wilmot, V. L., op. cit., pp. 21-23.

[6] Eng. and Min. Jour., Metal and Mineral Markets, vol. 21, no. 1, New York, McGraw-Hill Publishing Company, Inc., Jan. 1950.

blasting material. The bulk of this material in California is obtained from the natural sands bordering Monterey Bay. Here, by means of draglines, dune and beach sands are mined. The beach sand is replenished by wave action as fast as it is removed, and draglines have been operating at the same locations for several years. Some of this sand is marketed as it is taken from the beach, and some is dried, screened, and mixed to the buyer's specifications. The beaches of southern California, notably the El Segundo area, yield a small amount of sand-blasting sand for local consumption.

Small amounts of crushed rock, chiefly dacite porphyry, are also produced in California as sand-blasting material. Such material is quarried a few miles south of Corona, Riverside County. Being tough and angular, this crushed rock is an excellent blasting material; but its high cost restricts it to specialized uses.

The principal consumers of sand-blasting materials are shipyards, railroads, aircraft factories, and other metal-working industries. The increased industrial activity in California, particularly in the war-expanded shipyards and aircraft plants, has led to a marked rise in blasting-sand output. Blasting material of the beach-sand type is being marketed in the $5 to $10 per ton price range; crushed-rock blasting material is sold for approximately twice as much.

A small demand still exists for fabricated natural sandstone abrasives such as grindstones, pulpstones, and millstones. There are no plants in California producing such articles, however, and the demand for them is decreasing. These stones are obtained from massively bedded deposits, free from closely spaced joints, and containing sharp, well-sorted, and evenly cemented quartz grains.

Quartz and Quartzite. Quartz and quartzite may be ground and graded to produce a silica sand. Such material can be used for many of the abrasive purposes for which natural silica sand is used, and the ground material is generally sharper than the natural product. Quartz and quartzite are abundant in California but have not been mined as abrasive materials in appreciable quantities.

Grinding Pebbles. For more than 30 years a small annual production of grinding-mill pebbles has been obtained from deposits in California. Most of this production has come from San Diego County, where the pebbles are found along the ocean beach. The pebbles are of several rock types, and those of sufficient hardness and toughness for mill grinding must be selected by hand. Pebbles for grinding are discussed in more detail in a separate section of this bulletin.

Diatomite. California, the largest producer of diatomite in the world, accounts for about 98 percent of the United States production; but of this amount only an insignificant percentage is used as an abrasive. The abrasive uses of diatomite are mainly confined to metal polishes and dental powders. The occurrences of diatomite, and its other uses, are discussed in another section of this bulletin.

Tripoli. Tripoli is a porous, earthy substance composed almost entirely of silica. The name is loosely applied to many siliceous substances used for abrasives, but in a restricted sense it pertains to certain fine-grained rocks found in the Missouri-Oklahoma area. Tripolite from this area is an even-textured rock, the grains of which are mostly less than 0.01 millimeter in diameter. Tripoli is shaped into blocks for many abrasive and filtering purposes, and is also ground into a powder for cleansing and polishing. The origin of tripoli is uncertain, but it is thought to be a residual product of the weathering of siliceous limestones. No occurrences of tripoli have yet been noted in California.

Feldspar and Kaolin. Although the main consumption of feldspar and kaolin is for nonabrasive purposes, these minerals are important soft abrasives. Ground feldspar is the main ingredient of many household scouring powders, and kaolin has been used for polishing silverware. Feldspar and kaolin from California sources generally have not been marketed as abrasives, though a suitable supply is available. These materials are discussed more fully in separate sections in this bulletin.

Talc. A very small part of California's yearly talc production is used as an abrasive for polishing soft metals, leather, and rice grains. Talc, as a commodity, is discussed separately in this bulletin.

Pumice and Pumicite. Between 5,000 and 10,000 tons of the pumice and pumicite mined in California during 1948 were marketed as abrasive material. This was less than 5 percent of the state's total pumice and pumicite output for the year, most of which was used as lightweight aggregate.

Pumice and pumicite are volcanic rocks which differ only in particle size and degree of fragmentation. Pumice is a natural frothy glass formed from siliceous lava. It contains abundant air cells and commonly will float on water. Pumicite, also known as volcanic ash, is an aggregate of small glass shards, and is a product of the volcanic fragmentation of pumice. The geologic distribution of these materials in California and their uses are reviewed in the section on pumice and pumicite in this volume.

At seven localities in the state, pumice and pumicite have been mined in relatively large quantities as abrasive materials. In 1948, six of the operations were active. The volcanic rocks of these deposits range from late Tertiary to Recent in age and all have apparently originated from volcanism in the eastern portion of the state.

For more than 20 years a deposit of pumicite near Shoshone, Inyo County, has been worked intermittently and the product marketed as an abrasive. The pumicite is a layer interbedded with nearly horizontal Pleistocene lake beds. It averages 12 feet in thickness, and is extensively exposed. It is uniformly fine-grained and very friable. The production is shipped to the Los Angeles area where it is sold as a cleanser ingredient.

Pumice and pumicite for use as abrasive materials have also been produced from the Last Chance Canyon area of El Paso Mountains, Kern County. In this area a series of volcanic rocks containing pumiceous layers is overlain by pumicite-bearing lake beds. Both the volcanic rocks and lake beds are Pliocene (?) in age and are moderately deformed.

For a period of about 25 years previous to 1947 a pumicite layer in the Last Chance Canyon lake beds was worked by the Cudahy Company which used the product as an abrasive ingredient in Old Dutch Cleanser.[7] The layer averages 8 to 9 feet in thickness, and is interbedded with silicified lake sediments. Its exposures have been traced along strike for a distance of about 4 miles.

Pumice from the Last Chance Canyon volcanic rocks is being mined by the Calsilco Corporation and sold, in part, as an abrasive material.

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[7] Tucker, W. B., Los Angeles field division—Kern County: California Div. Mines and Mining Rept. 25, p. 76, 1929.

It is obtained from a layer 8 to 20 feet thick within basalt. The product is ground to different size grades. It is used in scouring powder and tooth powder, and in such nonabrasive applications as ceiling insulation, acoustical plaster, wood filler, and metallic paints.[8]

Pumice for use as an abrasive is also obtained from a deposit on the western slope of the White Mountains northeast of Laws, Mono County. The pumice deposit is a bed in a fanglomerate. It is approximately 20 feet thick and has been uncovered over an area approximately 600 feet long. The product is ground and used as a scouring powder and in other polishing and grinding compounds.

A pumice bed, exposed in Madera and Fresno Counties on both sides of the San Joaquin River near Friant, is also being worked for abrasive material. The bed is from 20 to 25 feet thick and is extensive.

Blocky pumice is being mined from a pumice dome near the north end of Mono Craters in Mono County. This material is relatively strong and compact. It is sawed to specified sizes at Leevining and the blocks are marketed for use as scouring material.

Scouring blocks are also being cut from pumice obtained at a deposit at Glass Mountain in the Medicine Lake Highland, Siskiyou County. Here pumiceous and scoriaceous material has formed as a surface phase of Recent obsidian flows.

Nearly all of the pumice and pumicite produced as abrasive material in California has been obtained from open cuts. Some of the development at the Cudahy property, however, employed underground methods.

ARTIFICIAL ABRASIVES

None of the three principal artificial abrasives has been manufactured in California, but natural materials are available in the state for the production of two of them, silicon carbide and boron carbide. These may well form the basis of a future artificial abrasive industry.

Silicon Carbide. Silicon carbide, known by the trade name ''Carborundum'' is the most widely used artificial abrasive. It has a hardness on the Mohs scale of 9.5 to 9.75, and is the lightest of the high-grade abrasives. The method used for preparing silicon carbide today is virtually the same as that used by its discoverer, Dr. E. G. Acheson, in 1891. It is a batch process in which iron-free, pure quartz sand or ground quartz and petroleum coke are placed in an electric furnace and fired for 36 hours. Silicon carbide forms in the center of the furnace as needle-like, highly irridescent crystals.[9] These crystals are then crushed, ground, and graded for use in grinding wheels, on abrasive papers, and in other abrasive products. All necessary materials for the manufacture of silicon carbide are obtainable in California.

Fused Alumina. Bauxitic clay in relatively small amounts has been used in California, but as yet none of this material has been used in the manufacture of fused alumina or artificial corundum.

Boron Carbide. Boron carbide, the hardest known manufactured substance, was first placed on the market in 1934, under the trade name

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[8] Tucker, W. B., and others, Mineral resources of Kern County: California Jour. Mines and Geology, vol. 45, p. 250, 1949.

[9] Eardley-Wilmot, V. L., Abrasives, artificial abrasives and manufactured abrasive products and their uses: Canada Dept. Mines, Mines Branch, Rept. 699, Pt. 4, pp. 1-14, 1929.

of "Norbide." It is chemically inert and almost as hard as diamond; however, its low tensile strength prevents its use as grit in grinding wheels. Boron carbide is used extensively as a substitute for diamond dust in cutting and polishing, and when heated to 2450° C. it can be molded into such useful items as sand-blasting nozzles and gage tips.

Boron carbide, like silicon carbide, is produced in an electric furnace. Water is evaporated from chemically pure boric acid crystals to form a glass-like anhydrous oxide. This oxide is mixed with high-grade petroleum coke, and placed in an electric furnace. The charge is fired, and at approximately 5000° F. boron carbide crystals (B_4C or B_6C) are formed. As California produces practically the entire world supply of borates, all the raw materials necessary for the manufacture of boron carbide are available in the state.

Artificial abrasive industries have been developed principally in areas where an abundant and economical source of electric power is available. At present there is no electric power surplus in California, although future hydro-electric development may remedy this situation.

ANDALUSITE, KYANITE, AND SILLIMANITE

By Lauren A. Wright

Andalusite, kyanite, and sillimanite, though minerals with different crystal structures, have the same chemical composition ($Al_2O_3 \cdot SiO_2$) and are used similarly as raw materials in refractory ceramic bodies. These minerals have been noted at numerous localities in California, but rarely are they in commercially exploitable concentrations. Two such concentrations, one of andalusite in Mono County, and another of kyanite in Imperial County, were mined nearly contemporaneously for a period of about 23 years. Together they have contributed a total of about 36,000 tons of aluminum-silicate rock, but in recent years both operations have been discontinued. Sillimanite has not been mined in the state, nor do any of the known occurrences promise to be commercial sources.

In California, as elsewhere, the minerals of this group are usually found in metamorphic rocks. Irregular distributions of andalusite and kyanite exist in pegmatite dikes and quartz veins, but are less common. Though many occurrences of andalusite, kyanite, and sillimanite are in schistose rocks, the andalusite and kyanite deposits that have been mined in California are both in massive quartzose units in areas that also contain much granitic rock.

Andalusite. The andalusite deposit is high on the west slope of White Mountain in Mono County; it is approximately 18 miles north of Bishop and 10 miles west of the California-Nevada line. For much of its active period, this mine was reported to be the world's only commercial andalusite source,[1] but andalusite has since been produced from a property near Thorne, Nevada.

Lemmon [2] has summarized the geology of the White Mountain deposits. The andalusite occurs in highly metamorphosed pre-Cambrian rocks which have been intruded by Mesozoic granitic rocks. The andalusite is

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[1] Jeffery, J. A., and Woodhouse, C. D., A note on a deposit of andalusite in Mono County, California; its occurrence and technical importance: California Min. Bur. Rept. 27, pp. 459-464, 1931.

[2] Lemmon, D. M., Geology of the andalusite deposits in the northern Inyo Range, California: Stanford Univ. Abstracts of Dissertations 1936-37, pp. 84-85, 1937.

confined to portions of a quartzite which is locally conglomeratic. Fine-grained schists in the sequence were derived from volcanic rocks. The andalusite bodies represent the contact metamorphism of aluminous sediments, and have been localized by faults and prominent joints.

> "No ore containing less than 60 percent andalusite has been mined. Developed reserves of this grade are meager. Lower-grade material suitable for concentration is much more abundant. The Vulcanus No. 8 claim contains, exposed on the surface, approximately 250,000 tons of material that averages about 40 percent andalusite." [3]

Additional data on the minerals and genesis of the deposits have been supplied by Kerr.[4]

The White Mountain property, first opened in 1922, was operated by Champion Sillimanite, Inc., which used the andalusite as a raw material in the manufacture of high-grade porcelain for spark plugs and chemical ware. The andalusite-rich rock was removed selectively by quarrying and stoping, and was hand-sorted at the mine before being transported by mule back and truck to Shealy, the nearest rail siding. From Shealy it was shipped to the company's Detroit factory.

In porcelain manufacture the andalusite was first crushed, then treated magnetically to remove the iron. It was mixed with clays and dumortierite, was molded, and was fired at about 3700° F. The high cost of andalusite production from this property and the introduction of synthetically prepared alumina (Al_2O_3) as an andalusite substitute in refractory ceramics were among the factors which in 1945 led to cessation of the White Mountain operation.

Kyanite. The state's only commercial kyanite source to date has been a locality in the southwestern portion of the Cargo Muchacho Mountains of Imperial County, about 3 miles northeast of the Ogilby rail siding.[5] In a geologic setting somewhat similar to that of the White Mountain andalusite, the Ogilby kyanite occurs as clusters of blue blades that persist throughout much of the quartz-rich portions of a highly metamorphosed pre-Mesozoic formation. Tourmaline and limonite are local constituents of the kyanite-bearing rock. In this area, as at White Mountain, intrusive granitic rocks are prominent. The kyanite-bearing rock is discontinuously exposed for a distance of about a mile along the west side of the mountains, but mining has been mainly confined to a single hill. Here a steeply dipping kyanite-rich mass with a maximum thickness of about 400 feet has been exploited by an open cut.

Concentrations of quartz in zones and pods within the main mass caused difficulty, and somewhat selective mining was required. However, most of the material that has been mined probably averaged more than 40 percent kyanite. Only a small portion of the kyanite-rich body was removed during this operation. Other bodies containing comparable quantities of kyanite are exposed in the area but have not been worked. Muscovite schist, a mica-rich metamorphic rock, forms a large part of the same formation and is currently being mined in a separate operation (see section on mica in this volume).

The Ogilby property was opened in 1925 by Vitrefrax Corporation of Los Angeles. The operation was controlled by this corporation until

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[3] Lemmon, D. M., op. cit.

[4] Kerr, P. F., The occurrence of andalusite and related minerals at White Mountain, California: Econ. Geology, vol. 27, no. 7, pp. 614-693, 1932.

[5] Henshaw, P. C., Geology and mineral resources of the Cargo Muchacho Mountains, Imperial County, California: California Div. Mines Rept. 38, pp. 147-196, 1942.

mining was discontinued in 1946. Treatment of the kyanite-bearing rock[6] involved heating to a temperature of 1700° to 1800° F. in a rotary kiln. Iron oxide was thus chemically reduced to allow a later magnetic separation. The same heat treatment converted alpha quartz to beta quartz, which was in turn reconverted to the alpha variety by quenching in water. The sudden expansion and contraction of the quartz, with but slight volume change in the coarser kyanite, caused a separation of the two minerals. Subsequent crushing, followed by washing over slightly inclined shaking screens, allowed removal of the quartz and retention of relatively pure kyanite blades. A mixture composed of the kyanite separate and other high-alumina material was then fused in an electric furnace. Final composition approximated that of mullite ($3Al_2O_3 \cdot 2SiO_2$). The finished products, marketed under the trade names "Argon" and "Durex" were used in the manufacture of a number of refractory ceramic products. The Vitrefrax Corporation, however, was liquidated in 1946 and the Ogilby deposit has since been idle.

The main kyanite sources in the United States have been in the southeastern states, principally Virginia, North and South Carolina, and Georgia, but from year to year there have not been enough producers to permit the consistent publication of production figures. Much of the kyanite used in the United States, however, is imported. India has been the principal foreign source of kyanite. Indian kyanite, when calcined, maintains its strength, instead of chalking. Much of the domestic kyanite does not have this property. The Indian kyanite is therefore particularly suited to the manufacture of such products as refractory brick and kiln furniture which require strength as finished products.

Prices and Markets. Most of the domestic andalusite and kyanite operations have been captive mines with an output consumed solely by the producer. None of the production of these minerals in California, for example, has been obtainable on the open market. A uniform product acceptable to refractory manufacturers, however, would doubtless find a steady, though small, market in the ceramic industry of the west.

Prices for domestic kyanite in 1947 ranged from $19.50 per short ton for crude kyanite to $37.50 for calcined material. The cost of Indian material laid down at Atlantic seaports was about $40 per ton.[7]

ARSENIC

By L. A. Norman, Jr.

Arsenic mineralization has been noted at many localities in California. The ores of numerous gold and silver deposits in the state are particularly rich in arsenic; other deposits consist principally of arsenic-bearing minerals. But only in 1924 was there a recorded production of arsenic at a California plant by treatment of ores obtained in the state. Arsenic is normally a by-product of the smelting of ores of other metals. Such ores mined in California, but treated at out-of-state smelters have probably yielded additional amounts of arsenic. Large quantities of arsenic compounds, mainly in the form of insecticides, are consumed in

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[6] Riddle, F. H., Mining and treatment of the sillimanite group of minerals and their uses in ceramic products: Am. Inst., Min. Met. Eng. Trans., vol. 102, pp. 131-151, 1932.

[7] Gwinn, G. R., Minor nonmetals: Minerals Yearbook 1947, pp. 1270-71, 1949.

California. Even though other chemicals may be substituted for arsenic compounds, the latter continue to be in great demand.

Mineralogy and Geologic Occurrence. The arsenic minerals include native arsenic, arsenopyrite ($FeAsS$), löllingite ($FeAs_2$), smaltite ($CoAs_3$), chloanthite ($NiAs_3$), niccolite ($NiAs$), tennantite ($3Cu_2S \cdot As_2S_3$), enargite ($3Cu_2S \cdot As_2S_5$), proustite ($3Ag_2S \cdot As_2S_3$), realgar (AsS), orpiment (As_2S_3), and many rare sulfarsenides of copper, silver, and lead. Arsenopyrite, which contains 46 percent arsenic, is a common constituent of many ores and is the principal source of commercial arsenic. But any arsenic mineral may be a source, if the method of ore treatment provides for arsenic recovery.

Arsenic minerals occur in almost all classes of sulfide deposits, though, according to Lindgren,[1] they are most plentiful in veins of the intermediate- and high-temperature type. Primary arsenic is generally believed to have originated in magmas, but arsenic deposits are not known as magmatic segregations.

Localities. In 1924 at a custom smelter at Bay Point, Contra Costa County, arsenic was recovered from California and Nevada ores. The localities from which these ores came was undisclosed. Appreciable amounts of arsenopyrite are contained in many of the gold-quartz veins of the Mother Lode and Grass Valley districts, and in the gold veins of Shasta, Trinity, Siskiyou, and other northern counties. The gold and silver ores of the Randsburg area in eastern Kern County have an unusually high proportion of arsenopyrite.

An attempt has been made to mine arsenopyrite at a deposit near Escondido, San Diego County. Here lenses and seams of arsenopyrite and pyrite occur in quartzitic masses which are enclosed by diorite.[2] The property is now idle.

Utilization.[3] More than half of the arsenic produced in the United States is consumed in the manufacture of insecticides, principally lead arsenate, calcium arsenate, and paris green (copper acetoarsenite).

The second largest use of arsenic is as a weed killer. High-grade white arsenic (arsenic trioxide) is used in glass manufacture as a decolorizer, opacifier, and refining agent. Smaller quantities of arsenic and arsenic compounds are used in wood preservatives, dyes, nonferrous alloys, pharmaceuticals and paints.

Markets. The availability of relatively cheap by-product arsenic makes it improbable that arsenic mining, as such, will be profitable in California in normal times. But arsenic may be obtained as a by-product of future smelting operations in the state. An important domestic factor is the large amount of arsenic that is now wasted in operating plants elsewhere in the United States. Production could be materially increased if demand made it economic to install the necessary equipment to handle this arsenic. An estimate of the United States production of crude and refined arsenic in 1948, based on production figures for the first 10 months of the year, approximated the 1947 figure of 18,755 short tons.[4] The

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[1] Lindgren, Waldemar, Mineral deposits, p. 633, 1933.

[2] Tucker, W. B., and Reed, C. H., Mineral resources of San Diego County: California Div. Mines Rept. 35, p. 12, 1939.

[3] Tyler, Paul M., and Potar, Alice V., Arsenic: U. S. Bur. Mines Econ. Paper 17, pp. 3-10, 1934.
Mote, Richard H., Arsenic: Minerals Yearbook 1946, pp. 137-142, 1949.

[4] Gustavson, Samuel A., 1948 annual review, arsenic: Eng. and Min. Jour., vol. 150, no. 2, p. 87, 1948.

important domestic producers in 1946 were the American Smelting and Refining Company plants at Tacoma, Washington, El Paso, Texas, and Murray, Utah; Anaconda Copper Mining Company at Anaconda, Montana; and the U. S. Smelting and Refining Company at Midvale, Utah.

Domestic production of arsenic, normally insufficient to meet domestic needs, is supplemented by imports. Imports of arsenic in 1948 are estimated to have been approximately 3,500 tons less than the 1947 imports of 13,940 tons.[5] Of this, Mexico supplied 75 percent.

The commercial specifications of white arsenic require that the product shall contain 99 percent or more arsenic trioxide; standard domestic brands contain 99.5 percent. Certain other specifications may be required by manufacturers of arsenic compounds to fit their particular needs. Compared to domestic grades, the average foreign product is less pure. Crude arsenic is grayish in color and contains 92 to 96 percent arsenic trioxide.

The price of refined white arsenic, arsenic trioxide, 99 percent, rose from 6 to 6.25 cents per pound on January 1, 1948, and remained at that figure throughout the year.

Preparation. The commercial methods of extracting arsenic from ores and the production of the more common arsenic compounds have been described by Smith.[6] Metallic arsenic is produced by the sublimation of arsenopyrite or löllingite in the absence of air, and by the reduction of arsenic trioxide with charcoal by retorting. Crystalline arsenic crusts form near the mouth of the retort while the pulverulent arsenic used in making arsenic compounds, is deposited in the cooler parts of the retort.

White arsenic is produced as a by-product in gold, copper, and lead smelting operations. When the arsenic-bearing ores are roasted, the volatilized arsenic collects in the cooling systems and bag houses. The crude arsenic fumes can then be refined by resublimation to remove impurities and to produce the desired purity and color. Calcium arsenate has been made directly from ores by a wet process, in which the ore was crushed and then ground with caustic soda solution in a ball mill and the calcium arsenate precipitated by the addition of milk of lime.

History of Production. The first and only recorded commercial recovery of arsenic in California was in 1924 when arsenic compounds were manufactured from California and Nevada ores by the Chipman Chemical Company at Bay Point.[7] Previously, in 1920, ore carrying 10 to 12 percent arsenic was shipped from the Grass Valley district to Tacoma, Washington, for treatment.

Prior to the first World War, Germany was the leading producer of white arsenic, although England had produced more arsenic at the height of the Cornwall tin mining operations. As new uses were developed and the accelerated demand for insecticides arose, world production increased, and the United States assumed the role of leading producer soon after the war. Mexico and Sweden are now the important foreign producers.

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[5] Gustavson, Samuel A., op. cit.

[6] Smith, W. C., Arsenic, in Liddel, D. M., and others, Handbook of nonferrous metallurgy, vol. 2, pp. 94-102, 1945.

[7] Bradley, Walter W., California mineral production for 1924: California Min. Bur. Bull. 96, pp. 38-39, 1925.

ASBESTOS

By Fenelon F. Davis

Small quantities of asbestos, one of the strategic mineral materials in which the United States is deficient, have been intermittently produced in California for many years. Massive serpentine, the host rock for most asbestos deposits, is widely distributed throughout California and in the future may yield asbestos from hitherto undiscovered deposits.

Mineralogy and Geologic Occurrence. Of the group of fibrous minerals known as asbestos, chrysotile ($H_4Mg_3Si_2O_9$), a variety of serpentine, accounts for about 96 percent of the world production. Chrysotile fibers are silky and flexible and have high tensile strength; when sufficiently long they are valued for spinning. Chrysotile is less resistant to heat and acid than most other varieties of asbestos.[1]

The classification amphibole asbestos includes the fibrous minerals anthophyllite $(Mg,Fe)SiO_3$, tremolite $(CaMg_3(SiO_3)_4)$, actinolite $(Ca_2(Mg,Fe)_5(OH)_2(Si_4O_{11})_2$, crocidolite $(NaFe(SiO_3)_2FeSiO_3)$, and amosite, an amphibole richer in iron than anthophyllite. Most crocidolite and amosite are suitable for spinning. Anthophyllite and tremolite are most valued for their resistance to acids. Asbestos production from California has been almost entirely of the chrysotile and tremolite varieties.

The chrysotile and tremolite deposits of California, like the large deposits in Quebec, are contained mostly in massive serpentine formed from the alteration of magnesium-rich ultrabasic rocks. The asbestos occurs in veins and veinlets in parallel or net-like arrangement. The value of a deposit is determined largely by the extent, width, and the closeness of spacing of the veins.

Asbestos mineral in the veins may occur as cross-fiber, where the fibers are perpendicular to the vein walls; slip-fiber, where the fibers parallel the walls; or mass fibers, with no discernable orientation. Though asbestos has been noted at many places in the large serpentine belts of California, at relatively few localities do concentrations exceed 5 percent, the grade above which deposits are considered to be of commercial interest.

The potential asbestos-bearing rocks, serpentine and its associated basic intrusives, are widely distributed in all the counties of the Coast Ranges, the Klamath Mountains, and the western foothills of the Sierra Nevada.

Asbestos deposits also may occur apart from serpentine masses. Commercial chrysotile bodies in Arizona, for example, are in dolomitic limestone and are associated with diabase sills. Metamorphic rocks of various types are known to contain amphibole asbestos.

Localities and History of Production. Asbestos has been produced and sold intermittently in small quantities in California since 1882.[2] Although 15 counties have reported asbestos production, and 17 additional counties have reported occurrences of asbestos since that date, no consistent production has been developed at any point in the state.

An average production of slightly more than 50 tons a year was maintained from 1887 to 1914, though in 1896-97 and in 1902-03 no asbestos was produced. Under stimulation of World War I, production

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[1] Ross, J. G., and Jenkins, G. F., Asbestos, in Industrial minerals and rocks, pp. 75-95, Am. Inst. Min. Met. Eng., 1937.

[2] Hanks, Henry G., Minerals of California: California Min. Bur. Rept. 4, p. 69, 1884, Bowles, Oliver, Asbestos: U. S. Bur. Mines Bull. 403, pp. 1-92, 1937.

more than tripled in 1915 and for several years following. From 1922-34 production continued at a 54 tons per year average, but from 1935-40 no asbestos was produced in California. Production was resumed in 1941 and has continued to the present at an average rate of more than 100 tons per year.

A chrysotile deposit 7 miles southeast of Copperopolis, Calaveras County, was one of the first to be systematically developed.[3] Work began in 1904 and continued intermittently until 1923. Equipment included a crusher, hammer mill, and compressor. A small tonnage of fiber was produced and used in acoustical and fire-proof plaster. Further experimental work was done in 1927.

A short-fiber chrysotile was produced in small quantities between 1917 and 1923 from a serpentine area near Washington, Nevada County.[4] The rock was mined in an open pit and crushed in a 20-stamp mill equipped with air-suction and fiberizers. The stamps were later replaced by crushing rolls.

Chrysotile in a serpentine belt on the southwest slope of Sampson Peak near Hernandez, San Benito County [5] was mined by hand methods between 1921 and 1925. The crude ore was run through a mill consisting of a crusher and some air-suction equipment. No dryer was included in the flow sheet, and the property was worked only during the dry season.

A small production of chrysotile from Monterey County and amphibole from Riverside County was reported in 1930. These were used for test purposes and as packing in the manufacture of automobile battery boxes, respectively.

Chrysotile produced in Napa County during 1933-34 was used for test purposes and for experiments in mill design. Short-fiber chrysotile was obtained from a deposit in Steel Canyon, Napa County,[6] from 1941-45. The ore was mined from an open cut. The mill consisted of a jaw-crusher, rotary dryer, two cyclones, shaking screens, two disintegrators, and a bagger. The product was used in plaster and stucco for fireproofing war-plant buildings.

Small lenses and pockets of tremolite in peridotite at Mears Creek in the northwestern corner of Shasta County [7] have been mined, and shipped from 1942 to the present. This fiber after hand sorting and shipping is processed by the Powhatan Mining Company and made into acid filter pads for the Gooch crucibles used in chemical laboratories.

A vein of white slip-fiber tremolite is found near Iowa Hill, Placer County, at the serpentine-slate bedrock contact in the old hydraulic-mine workings. The vein ranges from six to 15 feet in width and fibers 8 inches long have been reported. A small production of these fibers for use in acid filters has been reported from 1942 to the present.

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[3] Logan, C. A., Auburn field division—Calaveras County: California Min. Bur. Rept. 18, p. 98, 1922.

Logan, C. A., and Franke, Herbert, Mines and mineral resources of Calaveras County: California Div. Mines Rept. 32, p. 226, 1936.

[4] MacBoyle, Errol, Mines and mineral resources of Nevada County: California Min. Bur. Rept. 16, pp. 67-70, 1918.

[5] Laizure, C. McK, San Benito County: California Min. Bur. Rept. 22, pp. 223, 1926.

Averill, C. V., Mines and mineral resources of San Benito County; California Jour. Mines and Geology, p. 47, 1947.

[6] Davis, Fenelon F., Mines and mineral resources of Napa County: California Jour. Mines and Geology, p. 163, 1948.

Weaver, Charles E., Geology and mineral deposits of an area north of San Francisco Bay: California Div. Mines Bull. 149, 1950.

[7] O'Brien, J. C., Current and recent mining activities in the Redding district: California Jour. Mines and Geology, pp. 354-355, 1948.

Utilization.[8] Asbestos is of two commercial classes; spinning and non-spinning fiber. The long, strong, flexible fibers are spun into yarn, which is woven into heat-resisting fabrics such as brake linings, tape, and cloth. Chrysotile is best adapted to this use, although the better grades of crocidolite, amosite, and sometimes tremolite, can also be used. Some of the longer grades are used in magnesia block and pipe insulation consisting of 85 percent magnesia and 12 percent asbestos. Here, as well as in cements, plasters, and molded articles, the asbestos acts as a binder.

The shorter non-spinning grades are made into shingles, siding, and paper. The use of asbestos-cement pipe for gas, sewer, and water mains is increasing, as this pipe is resistant to acid and corrosion, and is non-conductive, and shock-proof. The fiber waste or shorts are used in making asbestos plaster, flooring, and as fillers in grease and paint. The best grades of tremolite and anthophyllite are acid-resistant and are used as filters in chemical laboratories. The low-iron variety of chrysotile found in Arizona is valuable in making electrical insulation tapes. Many new uses and adaptations for asbestos fibers are constantly being developed in the insulation and other industries. A typical example is the use of spray-coated insulation for metal, concrete, wood, and other surfaces.

Mining Methods and Treatment.[9] Because large commercial deposits of asbestos such as those in Quebec cover extensive areas, and the fiber content of the host rock averages only from 5 to 10 percent, open-cut large-tonnage operations are almost always employed in the early stages of development. The rock is blasted, loaded with power shovels, and trucked to the recovery plant. At a later period in the life of a property underground mining methods may be introduced. Both shrinkage-stope and block-caving methods have been successfully used for final-stage operations in the Canadian mines.

Milling[10] consists of separating the fiber from the barren rock by repetitive crushing, screening, and air-suction. A typical mill flow sheet would include primary and secondary rock crushing to 3-inch size, furnace drying to remove moisture, and third-stage crushing to free the fiber. The third-stage crushing product, about $\frac{1}{2}$-inch size, flows to a longitudinal shaking screen. Gravity concentration occurs as the material moves along the screen, producing a layer of light-weight fiber on top and a layer of heavier rock on the bottom. The light-weight fiber is removed through a suction hood installed at the end of the screen. The oversize rock flows over the end and the undersized rock drops through the screen. The oversize is crushed to $\frac{1}{4}$-inch size and rescreened as outlined above. The undersize is fed to a fiberizer, consisting of high-speed hammers which break the rock by impact, making a further separation of rock and short fibers. The latter are separated by another suction-screening operation. When free, the fiber is passed to a two-level screen for size classification. The shorts drop through both screens, the medium-length fiber is removed by air-suction from the end of the lower screen, and the long fiber is similarly removed at the end of the top screen.

Markets.[11] Many of the world's largest asbestos companies mine and mill the crude material at company-owned deposits, and then manu-

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[8] The uses of asbestos and asbestos products, in the Asbestos Factbook, 2d ed., pp. 9-15, Philadelphia, Secretarial Service, 1944.

[9] Smith, C. V., Asbestos mining methods: Asbestos, vol. 26, nos. 3, 4, 5, 1944.

[10] Kelleher, J. C., Milling asbestos: Asbestos, vol. 27, nos. 3, 4, 5, 1945.

[11] Ross, J. G., and Jenkins, George F., op. cit.

facture the finished products in their own plants. Other producers sell to consumers of raw material, either directly or through agents and mineral dealers. In the latter case it is customary for the producer or dealer to submit samples for the approval of the consumer. Sales contracts are usually based on the type and length of fiber, but may also specify fiber strength, color, flexibility, and chemical content.

In 1948 high-grade Canadian crudes and spinning fibers commanded an average price of $609 per short ton. Only one-tenth of 1 percent of the Canadian production was placed in this classification. An intermediate grade of Canadian fibers used in shingles and sheeting averaged $107 per short ton. About 34 percent of the production was in this category. Short fibers averaged $33 per ton, according to the Department of Mines. Province of Quebec, Canada.[12] Most of the production, 66 percent, fell in this class.

The price on amphibole asbestos produced in California in 1948 ranged from $50 to $200 per short ton depending on iron content and ignition loss.

The production of asbestos in the United States was approximately 34,000 short tons in 1948, and currently constitutes about 4 percent of the country's consumption. The sources of domestic chrysotile in 1948 were the mines of The Ruberoid Co., near Eden, Vermont, and mines near Globe, Arizona. Amphibole was produced in California, Georgia, and North Carolina. The difference between domestic production and domestic demand was balanced by the importation of 687,163 net short tons of asbestos minerals from foreign deposits. Canadian chrysotile from the province of Quebec accounted for about 94 percent of the imports, or 644,915 net short tons according to the U. S. Bureau of Census.[13] The remainder of the imported fiber originated chiefly in South Africa and consisted of amosite, crocidolite, and chrysotile. An extensive program of underground development and mill expansion is underway in Canada to meet the increasing demand for Canadian chrysotile.

ASPHALT AND BITUMINOUS ROCK

By Gordon B. Oakeshott

The use of natural California asphalt has been traced back to prehistoric time when Indians used it to caulk their plank canoes.[1] In the early development of roads in California, local sources of asphalt and bituminous rock were used for surfacing. In later years, natural asphalt was replaced by the heavy products of petroleum refineries which have proved to be more uniform, of higher grade, and to permit better control of specifications. The largest production of natural asphalt was during the years 1910 and 1911; in 1947-48 there was only one producer in the state. In the last few years there has been renewed interest in the large deposits of bituminous rock of central and southern California, as a possible source of raw material for power development, and as a direct source of petroleum.

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[12] Personal communication; also see Josephson, G. W., and Marsh, Dorothy I., Asbestos: Minerals Yearbook, 1946, p. 150, 1948.

[13] Monthly imports and exports: Asbestos, vol. 29, no. 11, May 1949.

[1] Heizer, Robert F., Aboriginal use of bitumens by the California Indians: California Div. Mines Bull. 118, p. 74, 1943.

Composition. Natural asphalt consists of heavy liquid, semi-solid, and solid hydrocarbon residues left when liquid petroleum migrates upward into surface and near-surface rocks and soil and loses its lighter fractions by evaporation. This process results in various types of accumulations of bituminous material, from seeps and pools of almost pure heavy petroleum to rock in which dry petroleum fills a fraction of the pore space. Such terms as "tar sand," "oil shale," and "asphalt rock" are included in the more general term "bituminous rock," which refers to any rock carrying a substantial amount of petroleum. The so-called "oil shale" in California contains hydrocarbons in the form of natural petroleum, while elsewhere, as near Rifle, Colorado, the term "oil shales" may refer to rocks that contain a carbon compound, referred to as kerogen, which is not petroleum, but which may be processed to yield petroleum products.

Various peculiar hydrocarbon substances which are usually considered as separate mineral species, but are closely related to asphaltum (the general name applied to pure solid asphalt), are found in widely separated localities in the Coast Ranges of California. Examples are *gilsonite*, found at Sisquoc in Santa Barbara County; *amber*, found in the Simi Valley in Ventura County; *curtisite*, occurring in serpentine in San Francisco, and with cinnabar in Lake, Napa, and Sonoma Counties; *aragotite*, associated with cinnabar in Napa and Santa Clara Counties; *napalite*, found in cinnabar mines in Napa County; and *posepnyte*, occurring in the cinnabar mines of Lake and Napa Counties. Chemically, they are hydrocarbons, consisting of compounds of hydrogen and carbon, often with oxygen also present. These peculiar hydrocarbon minerals have not proved to be of commercial importance in California.

General Geologic Occurrence. The bituminous materials that are found in bituminous sandstone and shale and in oil or tar seeps originated in organic shales and migrated in a fluid state into porous and permeable reservoir rock such as sandstone, conglomerate, diatomite, and fractured shale and chert. The organic source shales in California range in age from Upper Jurassic to Pliocene, but Miocene shale, including diatomite, is nearly always found in the areas of bituminous rock and appears to have been the major source of the petroleum. Large areas of bituminous rock represent oil sands or shales which have been exposed by erosion, allowing evaporation of the lighter petroleum fractions; the exposed sands may grade down dip into wet oil sands capable of yielding oil by drilling. In such rocks the natural tar seal aids in trapping liquid petroleum at depth. Tar seeps, deposits of asphaltum, and bituminous sandstone in zones of fracture, faulting, and severe folding, commonly occur along fold axes, at contact surfaces between different rock types, and along bedding planes in stratified rocks. Dikes and sills of bituminous sandstone are also common; some are large enough to be of commercial importance. Pressure from earth movements and overlying formations forces the easily deformed and relatively plastic oil sands along zones or planes of relative weakness.

Asphalt, bituminous rock, and tar seeps are found quite generally in the petroleum-producing areas of the state. In the early history of drilling in California, wells were most often located by such signs without regard to geologic formations or structure. The most northerly oil seeps in California are in southern Humboldt County, where they occur along fault contacts between Upper Jurassic Franciscan rocks and Lower Cretaceous (?) shale. Seeps and bituminous rocks are found at numerous localities in the Coast Ranges as far south as Orange County and around the borders of the San Joaquin Valley.

Localities. Localities in which bituminous rocks are known are very numerous, but they lie roughly within the limits of the distribution of marine Miocene formations in and around the margins of the Tertiary basins. Eldridge,[2] in a study of such deposits in the United States, gave a complete account of the occurrences in California, and included a map showing localities known at that time. Some of the largest exposures of bituminous rock are:

Mendocino County: 2½ miles north of the town of Pt. Arena; deposit 4 to 6 feet wide and 1½ miles long, in Monterey sandstone.

Marin County: 2 miles north of Bolinas, in Monterey shale.

Santa Cruz County: 6 miles along coast north of city of Santa Cruz; very extensive.

Santa Clara County: 2 miles west of Sargent, at oil field, at contact of Monterey shale and serpentine.

Monterey County: (1) 10 miles northeast of King City and 2 miles west of Lonoak, at contact of upper Miocene Santa Margarita formation and granite; (2) 10 miles southwest of Bradley at contact between Pliocene-Pleistocene Paso Robles formation and upper Miocene Salinas (Monterey) shale.

San Luis Obispo County: Very large deposit between Pismo, Edna, and north part of Arroyo Grande oil field, in the upper Miocene-lower Pliocene Pismo formation.

Santa Barbara County: (1) 4 miles southwest of Guadalupe; (2) 1 mile north of Casmalia, in Monterey shale; (3) In the old Santa Maria oil field in the upper Sisquoc (Pliocene?) and lower Foxen (Pliocene) formations; (4) 6 miles west of Zaca Lake and 2 miles east of Sisquoc; (5) Numerous outcrops along the coast from Gaviota to Santa Barbara, in the Monterey shale and overlying basal Sisquoc formation.

Ventura County: 4 miles east of Nordhoff.

Los Angeles County: (1) Dry-sand outcrops in Brea Canyon; (2) Rancho La Brea tar pits, near Salt Lake field, chiefly upper Pleistocene in age; (3) Extensive dry tar sandstone outcrops in northwestern Los Angeles County about 2 miles east of Newhall, chiefly of Pliocene age.

Kern County: Recent deposits 1 mile southwest of McKittrick.

In 1944 and 1945 the United States Geological Survey published a series of four preliminary maps, with brief texts on the same sheets, dealing with the occurrences of bituminous rock near Santa Cruz, Casmalia, Edna, and McKittrick. The following paragraphs summarize the results of this work and add a brief account of the bituminous sands east of Newhall, and the famous tar pits of Rancho La Brea in west Los Angeles.

Santa Cruz.[3] Two areas of bituminous rock are located from 4 to 6 miles northwest of Santa Cruz near State Highway 1 in the foothills of the Santa Cruz Mountains.

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[2] Eldridge, G. H., Asphalt and bituminous rock deposits in the United States: U. S. Geol. Survey, 22d Ann. Rept., pp. 365-452, 1900-01.

[3] Page, Ben M., and others, Geology of the bituminous sandstone deposits near Santa Cruz, Santa Cruz County, California: U. S. Geol. Survey Preliminary Map 27, 1945.

Cenozoic sediments cover the region and dip seaward at angles between 3° and 7°. Bituminous sandstone beds, which are present in the lower Miocene Vaqueros formation or just above it, range in thickness from 1 foot to 35 feet. The Vaqueros formation lies directly on pre-Cretaceous quartz diorite in this part of the Santa Cruz Mountains. Bituminous sandstone has also filled fissures in the overlying Monterey shale by upward injection and has formed numerous dikes and sills. In outcrop, the sandstone becomes light grayish or brownish in color as oxidation of the bitumens takes place. A barren overburden from a few feet to 100 feet in thickness would have to be removed to allow open-pit mining of the deposits.

The deposits were worked by several companies, including the City Street Improvement Company and the Cowell quarries, between 1888 and 1915. During that time more than 614,000 tons of bituminous rock, valued at $2,352,000, were produced and sold for paving. Output dwindled gradually to nothing in 1930. In that year Calrock Asphalt Company began quarrying in the adjacent area, using the material for paving and for making pressed asphalt bricks for industrial flooring.

Estimated reserves of bituminous rock in the two areas are 9,300,000 cubic yards, or about 10,000,000 barrels of asphalt. Bitumen content of the sandstone is ordinarily between 10 and 18 percent by weight.

Casmalia.[4] Diatomaceous mudstone rocks 5 miles north-northwest of Casmalia in secs. 3 and 10, T. 9 N., R. 35 W., in the Casmalia Hills, contain some petroleum.

Geologic formations in the area include the upper part of the upper Miocene Monterey shale, the upper Miocene-lower Pliocene Sisquoc claystone and diatomaceous mudstone, and the Pliocene Foxen mudstone overlying the Sisquoc formation. The upper member (Pliocene) of the Sisquoc diatomaceous mudstone, which is very porous and permeable, contains most of the oil. Structurally, the area is homoclinal, with beds dipping 20° to 40° NE., but bedding in the massive diatomite is often not clearly defined. Dikes or veins of asphaltum are common, and were actually mined underground during the early development of the area. Field evidence indicates that oil migrated into its present position shortly after uplift and folding.

Naturally burned oil-impregnated diatomite is common in the Casmalia hills. Some 5 miles southeast of the developed area, it was burned to a maximum depth of 200 feet in Recent time. Part of the burned shale is hard, brittle, brown, fused rock, and part of it is soft, earthy, brick-red material. The latter is quite similar to the material produced by artificial burning of oil-impregnated diatomite. The artificial product (discussed in the article on diatomite in this bulletin) is being used for lightweight aggregate, insulating concrete, and ornamental cement.

Bitumen from the region was used as early as 1885, first as fuel and then, about 10 years later, as street paving. In 1923 the N.T.U. Company extracted several thousand barrels of oil, but their project was unsuccessful, partly because of difficulties in the extraction process, and partly because the company was unable to meet the price of well-oil. N.T.U. closed its operations in 1928, and in 1930 the deposit was investigated by

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[4] Williams, M. Dean, and Holmes, Clifford N., Geology of oil-impregnated diatomaceous rock near Casmalia, Santa Barbara County, California: U. S. Geol. Survey Preliminary Map 34, 1945.

the Los Angeles Bureau of Light and Power as a possible source of fuel for power.

Exposures in the vicinity of the N.T.U. mine indicate a tonnage which would yield about 100,000 barrels of oil, but much of the oil-impregnated shale of the area is probably not exposed. One drill hole showed oil-impregnated strata to a depth of 625 feet. These strata contained from 39 gallons of oil per ton near the surface to 78 gallons per ton at a depth of 600 feet. The probable average content for the deposit is estimated at 42 gallons per ton. The oil content is not uniform, and no accurate estimate of reserves is possible without extensive core drilling.

Edna.[5] Very large deposits of bituminous sandstone and diatomaceous rocks have been worked near the Edna oil field 3 to 8 miles south and southeast of San Luis Obispo.

Here the lower Miocene Vaqueros formation is successively overlain by volcanics, the Monterey shale, the upper Miocene-lower Pliocene Pismo formation, and the Pliocene-Pleistocene Paso Robles gravels. The Pismo formation, which contains most of the oil, consists of conglomerate, sandstone, diatomaceous sandstone and shale, siliceous shale, and chert. Oil originated in the Monterey shale and migrated upward along the coarser beds and fractures into the more porous and permeable beds of the Pismo formation, losing its lighter constituents near the surface and leaving asphalt. The major structural feature of the region is the Pismo syncline on the flanks of which bituminous sandstone beds are exposed. Porosity and permeability, rather than structure, have controlled the occurrence of the bituminous materials. It is believed that folding took place during or shortly after oil-impregnation of the sandsone. The bituminous sandstone beds at depths of 500 to 1500 feet in the nearby Edna field yield a more fluid oil than that found in the outcrops.

In the Edna area are 27 quarries, some of which operated as early as 1887. Eighty thousand tons of bituminous rock were shipped for paving during the period 1887-90, and 75,000 tons during the period 1890-1915. In 1922 several adits intended to extract oil from the bituminous sandstone were driven by the California Oil Mining Company. The operation was unsuccessful.

It has been estimated that there are about 282,000,000 tons of accessible bituminous material in the Edna area, averaging about 11 percent bitumens by weight, or 26 gallons per ton.

In 1943 the Petroleum Field Office of the Bureau of Mines at San Francisco, in cooperation with the Geological Survey and the Petroleum Administration for War, initiated a study of bituminous sandstone in which the part of the Bureau was to study processes for extraction of the oil. Such a study [6] was made of the bituminous sandstone of the Edna district. It showed that high recoveries of hydrocarbons suitable for making fuel oil, Diesel fuel, and gasoline were possible if an especially developed modification of the hot-water separation method was used. The report includes data on the properties of Edna asphalt, distillation analyses of the bitumen, reduction to coke, and a detailed account of the recovery process.

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[5] Page, B. M., and others, Geology of the bituminous sandstone deposits near Edna, San Luis Obispo County, California: U. S. Geol. Survey Preliminary Map 16, 1944.

[6] Shea, G. B., and Higgins, R. V., Laboratory study of the hot-water process for separating hydrocarbons from surface deposits of bituminous sandstones near Edna, California: U. S. Bur. Mines Rept. Inv. 4246, 31 pp., 1945.

McKittrick.[7] Very large deposits of bituminous sandstone and asphaltic alluvium with numerous asphalt veins and seeps are found just southwest of the town of McKittrick, near the McKittrick oil field, along the eastern margin of the Temblor Range.

Geologic formations present include the Monterey shale, the lower Pliocene Etchegoin formation, the Pliocene San Joaquin formation, and the Pliocene-Pleistocene Tulare formation. Source rock for the bituminous materials was clearly the organic Monterey shale. The bituminous rock occurs in a highly faulted zone 100 to 1200 feet in width. Concentrations of asphalt occur along lithologic contacts, in fault zones, along fold axes, and in clastic intrusions. Most of the bitumen is in the Tulare formation.

Asphalt beds in the McKittrick area were first worked in the early seventies, and the asphalt was sent by wagon to Bakersfield. Though drilling was started at an early date to obtain oil to mix with the brittle asphalt, the earliest reported petroleum production in the McKittrick field was in 1887. The oil field is probably the oldest in the San Joaquin Valley.

The smallness and scattered spacing of individual deposits of bituminous materials and thick overburden hinder large-scale stripping operations. Reserves of bituminous material are estimated at 8,500,000 to 15,700,000 tons. From 4,850,000 to 9,000,000 barrels of bitumen are probably recoverable. This estimate is based on an average content of 10 percent bitumen in the sandstone or 24 gallons per ton.

Newhall. In an area about 2 miles east and southeast of Newhall in northwestern Los Angeles County, at the west end of the San Gabriel Mountains, is a group of small oil fields which includes Elsmere Canyon, Whitney Canyon, the actively developing Placerita field, and the old Placerita schist area. There are numerous active oil and tar seeps in the region. Seepages come from rocks of wide variety, including pre-Cretaceous gneisses and schists, Eocene conglomerate and sandstone, marine Pliocene sandstones, and lower Pleistocene gravel and sandstone. Bedded and massive bituminous sandstone is most extensively exposed in Elsmere and Whitney Canyons, and in an area extending from Elsmere into upper Grapevine Canyon. These exposures crop out over a large proportion of sec. 7, T. 4 N., R. 15 W., and sec. 18 and the N$\frac{1}{2}$ sec. 19, in T. 3 N., R. 15 W. The bulk of the bituminous rock is in the lower Pliocene Repetto formation (particularly the basal Pliocene Elsmere member) and the middle and upper Pliocene Pico formation. The region is one of complex folding and faulting; Pliocene and lower Pleistocene sediments dip northwestward off the pre-Cretaceous crystalline rocks of the San Gabriel Mountains. Penetration of the lenticular cross-bedded sandstone and conglomerate by petroleum has been highly irregular and has been controlled more by local variations in porosity and permeability than by structure. Seepages have been localized by faulting to some extent, but dikes of asphaltum and bituminous sandstone have not been found.

Though large quantities of bituminous sand are exposed, no estimate of tonnages is possible and no data are available on amounts of recoverable petroleum.

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[7] Page, B. M., and others, Bituminous sandstone deposits in the McKittrick district, Kern County, California: U. S. Geol. Survey Preliminary Map 35, 1945.

Rancho La Brea. The best known of all tar seeps, breas, or asphalt deposits in California is that of Rancho La Brea, in west Los Angeles adjacent to the Salt Lake oil field. These deposits have yielded one of the most remarkable assemblages of fossils ever found. Live oil springs have fed open ponds of heavy oil which have trapped and preserved a great variety of upper Pleistocene vertebrates including mastodons, ground sloths, horses, camels, sabertoothed tigers, and a host of other forms. Among the many published references to the tar pits is a paper by Stock [8] which describes the history of the area and the forms of life preserved. This paper includes a bibliography. No rocks outcrop in the vicinity of the tar pits, but a discussion of the nearby Salt Lake oil field by Soper [9] gives the geologic setting.

BARITE

By Lewis T. Braun

Occurrences of barite are widespread in California [1] and the mineral has been produced commercially at several localities. From 1910 to 1949 more than 500,000 tons of barite were mined in the state. Two properties have been recently active, one in Mariposa County, the other in Plumas County. In recent years these deposits have contributed slightly less than 5 percent of the national barite production. Although barite has a wide variety of industrial uses, most of California's production is used as a weighting agent in drilling mud.

Geologic Occurrence. Barite ($BaSO_4$) is the most common barium mineral. Its principal industrial uses stem from its relatively high specific gravity (4.3-4.6) and its insolubility in water or acids. Witherite ($BaCO_3$) is much less common than barite, but it has been used as a drilling-mud constituent and as a minor source of barium compounds. Although barium-bearing feldspars have been noted, barium is ordinarily not a prominent primary constituent of igneous rocks. In order of relative importance, commercial deposits of barite occur as (1) residual deposits derived from the weathering of barite-bearing rocks, (2) deposits which have replaced limestone or dolomite, and (3) vein deposits. The bulk of the United States barite production is obtained from the residual deposits in Arkansas and Missouri. Most California barite occurrences are either replacement or vein deposits.

Localities. A deposit near El Portal, Mariposa County, which is reported to have been operated as early as the eighties,[2] has been the principal source of barite in California. The deposit is unusual in that it has also yielded witherite in commercial quantities. The barite-witherite bodies appear to have replaced limestone layers in graphitic and slaty rocks. The replacement has occurred near the contacts of these metasediments with granodiorite masses. Outward from the granodiorite contacts the layers grade from calc-silicate rocks to witherite-rich rock to barite-rich rock.

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[8] Stock, Chester, Rancho La Brea, a record of Pleistocene life in California: Los Angeles Museum Pub. 1, April 1930.

[9] Soper, E. K., Salt Lake oil field: California Div. Mines Bull. 118, pp. 284-286, 1943.

[1] Murdoch, J., and Webb, R. W., Minerals of California: California Div. Mines Bull. 136, pp. 64-66, 1948.

[2] Fitch, A. A., Barite and witherite from near El Portal, Maripsoa County, California: Am. Mineralogist, vol. 16, no. 10, pp. 461-468, 1931.

Barite is currently being mined in Plumas County from a property near Greenville, where a lens of barite, measuring approximately 175 feet in length, 30 feet in maximum width, and 60 feet in depth, occurs in slate.[3] Near the walls of the lens, the barite and slate are interlayered.

Appreciable quantities of barite have been produced in Nevada County. During the twenties the Democrat mine [4] in Nevada County was the largest barite producer in the state. The barite body at this deposit ranged in surface width from 15 to 24 feet and was 250 feet long. Most of this body has been mined; the deposit has not been worked for many years.

The Spanish Mine [5] near Graniteville, Nevada County, which was worked during the period 1939-46, also yielded considerable quantities of barite. The barite body, which is contained in a country rock of schist and slate, is more than 300 feet in surface length, and has a maximum surface width of 7 feet. Thicknesses of as much as 15 feet were encountered underground.

Barite has also been obtained from several deposits in Shasta County.[6] In 1931, a few thousand tons of barite were mined by the Glidden Company near Castella. The property has not been operated since, although additional reserves are reported to exist. The ore body is tabular, and a few thin beds of sand are found within it. The barite may have been deposited by a spring carrying barium salts, issuing from a vent in the ocean floor.[7]

The Afterthought prospects, 20 miles north of Redding, have been located on barite veins occurring in basic igneous rock, probably gabbro.[8] These veins, which are traceable for 1000 feet, pinch and swell, and are as much as 6 feet thick.

Barite is a common gangue mineral in many of the metalliferous veins in the state, notably in the Calico and Barstow silver districts of San Bernardino County; but barite from these deposits has not been marketed. In 1927, a small amount of barite gangue from a quicksilver property in Orange County was recovered and marketed.[9]

Utilization and Markets. Of the 835,818 tons [10] of barite consumed in the United States in 1947, weighting oil for well-drilling mud used 56 percent. Twenty percent of the 1947 national consumption was used to manufacture the white pigment lithopone, a mixture composed of approximately 70 percent barium sulfate and 30 percent zinc sulfide. Thirteen percent was consumed in the manufacture of barium chemicals. The remainder was used in the manufacture of glass, as a filler in paint and rubber, and for numerous miscellaneous uses.

The Baroid Sales Division of the National Lead Company, which operates El Portal deposits, markets the output of this property as a drilling mud weighting agent. Both barite and witherite are utilized

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[3] Averill, Charles V., Mineral resources of Plumas County: California Div. Mines Rept. 33, p. 92, 1937.

[4] Bradley, W. W., Barite in California: California Div. Mines Rept. 26, p. 53, 1930.

[5] Bradley, W. W., op cit.
Logan, C. A., Nevada County: California Div. Mines Rept. 37, pp. 378-379, 1941.

[6] Averill, Charles V., Shasta County: California Div. Mines Rept. 35, pp. 114-115, 1939.

[7] Averill, Charles V., op. cit.

[8] Averill, Charles V., op cit.

[9] Bradley, W. W., op. cit.

[10] Houk, L. G., and Barsigian, F. M., Barite: Minerals Yearbook 1947, p. 164, 1949.

for this purpose, and marketed under the trade name "Baroid." The Plumas County property is operated by Barium Products Ltd., which manufactures barium chemicals at its Modesto, California, plant.

The National Lead Company and Barium Products Ltd. mine a large portion of their barite requirements in Nevada and bring the raw material to California for processing. In manufacturing lithopone, the Chemical and Pigment Company of Oakland uses Nevada barite exclusively. This company owns the Democrat mine and Glidden property in California, but does not operate them, as the large tonnage they require can be more economically mined from their large Nevada deposits.

The average reported value per ton per year of California barite has fluctuated from a low of $1.51 to a high of $15, but has averaged about $6. A large percentage of this production was utilized by the producers, and these figures do not represent a true market value for crude barite.

During August 1949, crude barite ore from Georgia was selling for $11.50 to $12 per long ton, and Missouri crude ore (94 percent $BaSO_4$) was selling for $9.50 per ton.[11]

BERYLLIUM

By Lauren A. Wright

Beryllium has had no commercial source in California, nor is production of the metal imminent from any of the state's known beryllium-bearing mineral localities. Nevertheless, beryl ($Be_3Al_2(SiO_3)_6$), the principal ore mineral of beryllium, is well known to California mineral collectors, chiefly for its occurrence in the pegmatites of southwestern Riverside and northern San Diego Counties. Here the beryl, though to date found only in curiosity quantities, is characteristically aquamarine or pink in color and is unusually transparent. These properties lend the mineral value as gem material.

Beryl occurrences are relatively uncommon elsewhere in the state, but they have been noted in Fresno, Inyo, Plumas, Trinity, and Tuolumne Counties.[1]

Beryl concentrations that can be commercially exploited for the metal are almost invariably in pegmatite dikes. Such dikes, which are found in areas in which granitic rocks are also exposed, provide the most likely field for the beryl prospector.

Beryl occurs as distinct hexagonal crystals or as irregular masses; some concentrations of pure beryl weigh as much as several tons. Beryl ranges in color from emerald green, light green, or blue, to flesh, white, or pink, and often it can be distinguished from quartz only with difficulty. Beryl concentrations are commonly confined to certain layered pegmatite zones which roughly parallel the borders of the dike.

In the past only the beryl masses large enough to sort by hand have been mined, and finely disseminated beryl has not been recoverable. In

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[11] Eng. and Min. Jour., Mineral Markets, vol. 20, no. 31, New York, McGraw-Hill Publishing Company, Inc., August 1949.

[1] Murdoch, Joseph, and Webb, R. W., Minerals of California: California Div. Mines Bull. 136, pp. 70, 71, 1948.

recent years, however, the concentration of beryl ores has been attempted, and in 1945 flotation patents were granted Bureau of Mines technicians.[2]

In 1941 a large iron-rich contact-metamorphic deposit in southeastern New Mexico was found to contain the beryllium-bearing silicate, helvite, as a minor, and locally as a major, constituent. Bodies of potential beryllium ore were subsequently outlined in this area.[3] Contact-metamorphic deposits in California may well be prospected for similar helvite occurrences.

Beryllium is used principally in alloys with copper. Copper alloyed with 2 percent beryllium has unusually high tensile strength and fatigue resistance. Beryllium also is fabricated into x-ray tube windows and atomic energy apparatus. Beryllium oxide and zinc-beryllium silicate are used as phosphors in fluorescent lamps; beryllium oxide is also a constituent of certain refractories.

Beryl sources in the United States have never exceeded a 400-ton annual production of the mineral; in recent years domestic production has been less than one-tenth the imported amount, which has come principally from Brazil.

In 1948 the price of domestic beryl, f.o.b. mines, rose from $16-$18 to $24-$26 per short-ton unit of BeO.[4]

BLACK SANDS

By Gordon B. Oakeshott

In California, gold, magnetite, ilmenite, garnet, and the platinum group are the principal minerals which may give black sands commercial value. They have been discussed elsewhere in this bulletin under the appropriate headings.

Black sands in California have been of interest to miners and prospectors since the discovery of gold more than 100 years ago. This interest has periodically been fastened on one or another of the heavy minerals found associated in sands. From early days to the present, gold has been the chief mineral recovered commercially from black sands, but the platinum-group minerals began to receive attention in the late nineties. In 1905 magnetite in sand was considered as a possible source for iron. During World War II attempts were made to recover chromite from black sands. In recent years interest has centered around ilmenite, zircon, and monazite from sands. Monazite is the principal source of the radioactive element thorium, a potentially valuable material in the development of atomic energy.

The United States Bureau of Mines has recently set up a project at Marysville to investigate the black sand resources in certain California placers.

Mineralogy. The term ''black sands'' has been applied to concentrations of heavy minerals having a specific gravity above three. Many, but not all, of these heavy minerals are black or dark colored. Day and Richards[1] made an early study of black sands in the placer mining

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[2] Nighman, C. E., Beryllium: Minerals Yearbook 1945, p. 816, 1947.

[3] Jahns, R. H., Beryllium and tungsten deposits of the Iron Mountain district, Sierra and Socorro Counties, New Mexico, with a section on the beryllium minerals by Jewell J. Glass: U. S. Geol. Survey Bull. 945E, pp. 44-79, 1944.

[4] Merrill, C. W., Minor metals: Eng. and Min. Jour., vol. 50, no. 2, p. 86, Feb. 1949.

[1] Day, David T., and Richards, R. H., Useful minerals in the black sands of the Pacific coast: Mineral Resources U. S., 1905, pp. 1175-1258, 1906.

regions of the Pacific. They found the minerals occurring most frequently in the placer sands were magnetite, gold, ilmenite, garnet, zircon, hematite, chromite, platinum, iridosmine, mercury, amalgam, olivine, iron silicates, pyrite, monazite, copper, cinnabar, cassiterite, and corundum. The preponderance of the mineral magnetite in these heavy sands is responsible for their black color.

Geologic Occurrence. The heavy minerals of black sands are concentrated in alluvial deposits because of the high specific gravity of those minerals and their resistance to chemical and mechanical weathering. They are found chiefly in the sands of streams, ocean beaches, bars, dunes, and terraces, of older geologic ages as well as Recent. Large amounts of heavy sand have been artifically concentrated in the hydraulic tailings, dredge trailings, placer clean-up sands, and dredge clean-up sands in the gold placer districts of California.

Source rocks from which heavy minerals are derived.

Mineral	Most common source rock
Magnetite	Very common in small amounts in most rocks. Consequently magnetite is the most abundant mineral in heavy sands in California.
Ilmenite	Common in small amounts in most rocks, often with magnetite. In large amounts in such rocks as gabbro, anorthosite, and pyroxenite.
Gold	Quartz veins in crystalline rocks; chiefly associated, in California, with the series of late Jurassic intrusions and older intruded rocks of the Sierra Nevada.
Garnet	Common in many crystalline rocks; most common in certain pre-Tertiary schists and granitic rocks.
Zircon	Common in small proportions in the acid intrusive rocks; most common in granite, syenite, and in pegmatites.
Hematite	Very widely distributed in many rock types.
Chromite; platinum group	Chiefly in ultrabasic rocks, including peridotites and serpentine.
Mercury; amalgam; copper	In the gold placer sands because of the mining operations and processes.
Olivine; iron silicates	Most common in the more basic crystalline rocks; very widespread.
Pyrite	Most common in association with metallic ore deposits.
Monazite	Mostly in pegmatites.

Production and Utilization. The large number of mineral constituents of possible commercial value in black sands is one of the principal reasons for the long-continued interest in these sands. To date, gold and the platinum-group metals have been the chief minerals recovered from California sands. Edman,[2] in an early report, discussed the value of black sands, and called attention to the fact that the ilmenite and chromite content interfered with the utilization of the sands as iron ore. He also noted the sporadic occurrence of heavy sands, and the lack of deep or extensive deposits.

Black sands near Aptos, Santa Cruz County, and Redondo Beach and Sand Canyon in Los Angeles County, have been utilized because they contain a high percentage of ilmenite and magnetite.

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[2] Edman, J. A., The auriferous black sands of California: California Min. Bur. Bull. 45, 1907.

At Aptos, the black sands that accumulate on the beach, have been utilized intermittently by several companies for many years.[3] The Triumph Steel Company was successful in metallurgically producing sponge iron, briquetted magnetite, alloy steel, and ferrotitanium, but was apparently unable to show a profit in its operation.

The Live Oak mine has been operating an electromagnetic mill in Sand Canyon in Los Angeles County for the past several years; the mill was designed to separate magnetite and ilmenite from Recent stream sands in the canyon. Some of the ilmenite concentrate was sold in 1947-48 to the San Gabriel Pigment Company at Roscoe, where it was used to manufacture titanium pigments.

In 1926 two experimental plants were in operation at Hermosa Beach,[4] using titaniferous sands from the beach between Redondo and Palos Verdes. One plant, with a capacity of 1200 cubic yards of sand per day, was making a magnetic separation of ilmenite and magnetite and was experimenting with the manufacture of titanium oxide. The other plant in operation was using the Bichowsky process to make titanium nitrite.

None of the operations utilizing sands for their titanium content was active at the close of 1948.

During World War II an attempt was made to obtain chromium from magnetite-chromite sands in San Benito County. A private operator worked on stream sands in Clear Creek not far from Hernandez. The operation was unsuccessful because there was not enough sand carrying sufficient chromite.

Recent interest in black sands has been largely for their ilmenite, rutile, zircon, and monazite content. The bulk of the United States production from black sands is from the dunes near South Jacksonville, Florida. There all four minerals are found in the one sand. According to the Bureau of Mines,[5] all zircon produced in the United States in recent years came from Florida. Consumers in the United States in 1947 received more than 27,000 short tons of zircon, an all-time high. Its most important uses, in order, are for refractories, vitreous enamels, electrical and chemical porcelain, metal and alloys, and pottery glazes. Fine crystals of zircon are used as gems.

The chief foreign sources of zircon are Australia and Brazil. California has produced little, although the mineral is a common constituent of the gold placer sands. The first production of commercial zircon in this state was reported in 1937. This was from a dragline dredge near Lincoln, Placer County. It was used in blasting sand, and for experimenting in the manufacture of refractories. A small amount was also shipped from Lincoln in 1941, for use in a steel alloy.

Monazite, a complex phosphate of several rare-earth elements and thorium, is the most important source of rare-earth elements. The principal use for these elements is in the cores of positive-arc electrodes for floodlights and projectors where the oxides and fluorides are required.

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[3] Laizure, C. McK, Santa Cruz County: California Min. Bur. Rept. 22, pp. 82-84, 1926.

Hubbard, Henry G., Mines and mineral resources of Santa Cruz County: California Div. Mines Rept. 39, pp. 35, 42-43, 1943.

[4] Tucker, W. B., Los Angeles County: California Min. Bur. Rept. 23, pp. 298-299, 1927.

[5] Matthews, A. F., Minor metals: Minerals Yearbook 1946, p. 1282-1284, 1948.

Cerium dioxide is used as a fine abrasive for polishing glass. Because monazite contains the radioactive element thorium, a possible source for atomic energy, statistics on monazite are not released. Efforts are being made to develop domestic deposits. There are no known natural concentrations of monazite sands of commercial importance in California. Day and Richards[6] found sands near Crescent City that contained as much as 56 pounds of monazite per ton of sand concentrate; they also found sands near Nevada City that contained as much as 4 pounds per ton of concentrate.

The determination of heavy minerals and their relative percentages has been one method used in subsurface correlation of sedimentary beds in the oil fields.[7]

Markets. The commercial minerals present in black sands are separated and marketed as concentrates. Market quotations on these minerals are given under the appropriate headings elsewhere in this bulletin.

CALCITE (OPTICAL)[1]

By Lauren A. Wright

High-grade optical calcite or Iceland spar has long been used in the manufacture of polarizing prisms which are employed in several types of optical instruments. Previous to World War II annual requirements probably seldom, if ever, exceeded 500 pounds for the world, or 200 pounds for the United States. Suboptical calcite, for which the specifications are generally less rigid, was in little demand previous to 1943. But in 1943 and 1944 approximately 10,000 pounds per year were consumed, principally in the manufacture of optical ring gun sights. During this period the demand for high-grade optical calcite also rose, but since 1944 the consumption of both types has dropped sharply. In the future an increased use of artificially prepared substitutes may contribute to a further decline.

Domestic production of optical calcite has been confined to a few localities in the western United States, but in normal times none of these deposits has proven capable of sustaining a profitable operation. During World War II a large portion of the domestic output was obtained from a deposit in San Diego County, California. In the early twenties appreciable amounts of optical calcite were also mined from a deposit in Modoc County.

Mineralogy and Geologic Occurrence. Calcite is one of the most common and most widely distributed of all minerals, but rarely does it occur in large, well-crystallized, transparent, single crystals suitable for optical use.

High-grade optical calcite must be colorless, and free from clouds, cavities, microscopic inclusions, twinning lamellae, and cleavage fractures. It must be in masses large enough to yield cleavage rhombohedra 3.5 centimeters long, 1.8 centimeters wide, and 1.8 centimeters thick. These specifications must also be met by suboptical calcite, except that

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[6] Op. cit.

[7] Tickell, F. G., The correlative value of the heavy minerals: Am. Assoc. Petroleum Geologists Bull., vol. 8, pp. 158-168, 1924.

[1] Fries, Carl, Jr., Optical calcite deposits of the Republic of Mexico: U. S. Geol. Survey Bull. 954-D, 1948.

faint color and clouds are permissible and cleavage rhombohedra should measure at least 2.86 centimeters on a side.[2]

Optical calcite deposits characteristically occur in areas of Tertiary or Quaternary volcanism and most are contained in the volcanic rocks themselves. The deposits have formed at shallow depth in cavities or open fissures, into which the crystals have grown with little interference, and generally unaccompanied by other minerals. Most deposits are pockety and must be mined on a small scale.

Localities. The Elzie Bagley optical calcite property,[3] in the Warner range 10 miles south of Cedarville, Modoc County, was worked intermittently during the period 1920-25, but has since been idle. The calcite is contained in basalt and occurs as veins, from a few inches to 3 feet thick. Some crystal aggregates reportedly weighed from 60 to 80 pounds, but few, if any, individual crystals weighed more than 12 ounces. Most of the crystals were imperfect and too small, but the usable ones were described as of excellent optical quality.

The total output of the property was relatively small. About 1000 ounces of optical calcite were sold in the winter of 1920-21, which was probably the mine's most active period. The mine workings consist of a single open cut, 25 feet long, 4 feet wide, and 15 feet in maximum depth.

Calcite deposits in northeastern San Diego County [4] had been known for many years, but were worked for the first time during World War II. The deposits are at the southern end of the Santa Rosa Mountains, 7 miles west of Truckhaven on U. S. Highway 99. They are in four principal groups, known as the Central, Heather, Defiance, and Victory areas. Of these the Central area has been the most productive.

The calcite has formed in pockets and in vertical fissures in sandstones and conglomerates of the Palm Springs (middle Tertiary) formation. The best deposits occur at the intersections of sets of joints. The joints themselves are ordinarily barren for most of their length.

The calcite crystals are tabular and range in size from minute flakes to plates as much as 18 inches in diameter and 3 inches thick. The average usable plate mined was from 2 to 3 inches in diameter and from a quarter to three-eighths of an inch thick.[5]

Mining was done mainly by open cuts, of which there are about 75 in the four areas. Many of them uncovered little or no calcite. None of the calcite bodies was found to be laterally or vertically continuous. The largest cuts, which are about 30 feet deep, were bottomed in rock barren of calcite. Three shafts were sunk below the best lenses that were uncovered in the open cuts, but downward continuations were not found. Numerous undiscovered pockets, however, probably remain in the area.

The property was active from late 1942 to early 1944 and more than 6000 pounds of calcite were shipped; but not all of this output was

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[2] Fries, Carl, Jr., op. cit., p. 113.

[3] Hughes, H. H., Iceland spar and optical fluorite: U. S. Bur. Mines Inf. Circ. 6468, p. 11, July 1931.

Unpublished data on the Elzie Bagley property has been supplied by Spangler Ricker, Engineer, U. S. Bureau of Mines, July 1949.

[4] Durrell, Cordell, and Bell, G. L., Calcite mines in northeastern San Diego County, California: U. S. Geol. Survey Press Notice, Nov. 30, 1944.

Additional data on the northeastern San Diego County calcite deposits have been supplied by Mr. John A. Burgess in a personal communication.

[5] These average thicknesses are much less than the minimum acceptable dimensions given by Fries, op. cit.

reportedly of usable grade. The calcite was used by the Polaroid Company in the manufacture of gun sights.

Markets and Prices. "The price of high-grade optical calcite varies widely, depending partly upon the urgency of the need and partly upon the size and quality of the individual pieces. The quality can be closely judged only by a trained observer in the laboratory. High-grade optical calcite in pieces weighing less than a pound have sold during the past few years for from \$5 to \$40 a pound, but very large pieces have sold for much more. * * *

"There had been no well-established market for suboptical calcite until late in 1942. At that time the Polaroid Corp. began to make large purchases, and by 1944 it had established the price of material, judged by examination in its laboratories to be usable, at \$7.50 a pound. Purchases of suboptical calcite by independent buyers, from 1940 until 1945, had been made at prices ranging from \$0.50 to \$12 per usable pound. Since November 1944, when the Polaroid Corp. discontinued its purchases of suboptical material, there has been no established price." [6]

CEMENT

By Oliver E. Bowen, Jr.

The value of portland cement produced in California is now second only to the value of petroleum products. Cement plants are centered around the two main marketing areas, San Francisco and Los Angeles. Most of the minerals used in these plants are mined in California. Although present production is great, far greater demands could readily be met by available California raw materials; some of these are less conveniently situated than those now being exploited.

Nature and Geologic Occurrence of Raw Materials Used in Portland Cement. The three essential constituents used in portland cement manufacture are calcium carbonate ($CaCO_3$), alumina (Al_2O_3), and silica (SiO_2). High-calcium limestone is the most common source of calcium carbonate; some form of clay usually supplies the alumina and silica. In sulphate-resistant high-iron cements, ferric oxide (Fe_2O_3) may be used in place of alumina to a considerable extent; most portland cements contain some iron oxide as a variable constituent of clays and clay shales.[1]

In California, limestone, argillaceous limestone, and sea shells are the sources of calcium carbonate; clays, clay shales, and the shaly fraction of argillaceous limestone provide the alumina and most of the silica; quartzite or sandstone may provide additional silica when needed. Iron oxides are supplied by magnetite-hematite ores and pyrites cinder (residue from sulphuric acid manufactured from pyrite).

Gypsum ($CaSO_4 \cdot 2H_2O$) in quantities of 2 to 3 percent is mixed with ground clinker to retard the setting time of a concrete mixture. Although there are large gypsum deposits in California, this is one of the few cement raw materials imported into the state. This is largely because the principal deposits are controlled by one or two companies which market the bulk of their output for products other than portland cement. Monolith Portland Cement Company operates its own gypsum

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[6] Fries, Carl, Jr., op. cit., p. 137.

[1] Bogue, R. H., The chemistry of portland cement, 539 pp. New York, Reinhold Publishing Co., 1947.

quarries in Ventura County, but Kaiser Company imports gypsum from its properties on San Marcos Island in the Gulf of California off Santa Rosalia. Considerable gypsum is shipped in from Nevada for use in portland cement. Bauxite for high-alumina cement also comes from out-of-state sources, although certain white clays from Ione, Amador County, have been substituted for bauxite.

With few exceptions, the limestones mined in California are metamorphosed marine sedimentary rocks, most of which are Paleozoic. Many California crystalline limestones have an appreciable content of magnesium, a highly detrimental ingredient if the rock is to be used for portland cement. As the magnesium content may vary widely within a given limestone deposit, close sampling and testing are necessary before and during exploitation.

Clay, which is essentially hydrous aluminum silicate, is supplied to cement plants in a number of forms. Clay shale, in which the clay is mixed with other silicate minerals as well as oxides and silica, is the most widely used form, principally because of its wide distribution and easy accessibility. Magnesia-rich shales are undesirable and close control of the chemical composition must be exercised. Transported and residual clays which are relatively free of nonaluminous debris are usable for cement, and in many ways are superior to clay shale. Large bodies of residual and alluvial clays, however, are not always readily accessible and their use may not be economically feasible, owing to high transportation costs.

In addition to the iron oxide provided by iron ores mined in California and by pyrites cinder, iron oxide is obtained in certain clays and clay shales that are used as cement materials.[2]

One California plant is unique in that it uses sea shells and mud dredged from San Francisco Bay as its principal raw materials.[3] Shell limestone is nearly pure $CaCO_3$ and hence is a superior source of CaO. Mud dredged with the sea shells is a satisfactory substitute for clay or shale.

Mining and Manufacturing Methods. Most limestone and clay deposits are mined by open-pit methods, but two California operations employ underground mining. Clays and shales normally can be removed without use of explosives, but most California limestones must be blasted. Transportation from quarry to processing plant is by truck, rail, or both. Specially designed side-dump trucks, trailers, and railroad cars are used.

The various rock ingredients are first crushed to convenient size in gyratory or cone crushers, and then finish-ground to easily-clinkered dimensions. Tolerances to which the raw material is crushed and ground depend upon the type of processing equipment used. There is a great deal of variation in equipment employed, and in processing methods.[4] Ground materials are fed into rotary-type kilns in proportions fixed by the analyses of the raw materials and the type of cement to be produced. Most high-alumina and high-iron cements require additions of bauxite and iron oxide respectively. The ingredients are then calcined and

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[2] Eckel, E. B., Cements, limes, and plasters, pp. 276-337, New York, John Wiley and Sons, Inc., 1922. See also Myers, W. M., Cement materials, in Industrial minerals and rocks, 2d ed., pp. 158-180, Am. Inst. Min. Met. Eng., 1949.

[3] Senior, S. P., San Mateo County: California Div. Mines and Mining Rept. 25, pp. 247-251, 1929.

[4] Kivori, A. M., Milling at Permanente cement plant: Am. Inst. Min. Met. Eng. Trans., vol. 148, pp. 374-397, 1942.

clinkered in rotary-type kilns under controlled-temperature conditions. The clinker is then ground and bagged or placed in bulk containers for shipment to market. Both wet and dry methods of manufacturing are used in California; wet-method and dry-method plants are about equally distributed. Gypsum is added either just before or after the final grinding of the clinker.

Centers of Production. The principal cement production and distribution centers in California are: The Colton-Riverside district, Riverside and San Bernardino Counties; Victorville-Oro Grande district, San Bernardino County; San Andreas, Calaveras County; Davenport, Santa Cruz County; Permanente, Santa Clara County; and Redwood City, San Mateo County. Most limestone and clay quarries are close to the processing plants.

Localities most favorable for future development of the cement industry appear to be the Sierran foothills of northern Tuolumne County; central Shasta County; the southwestern Mojave Desert, San Bernardino County; and the Wrightwood district in Los Angeles and San Bernardino Counties. These areas have large reserves of high-calcium limestone and are within 30 miles of rail facilities. The Cushenbury district on the north slope of the San Bernardino Range has particularly large resources

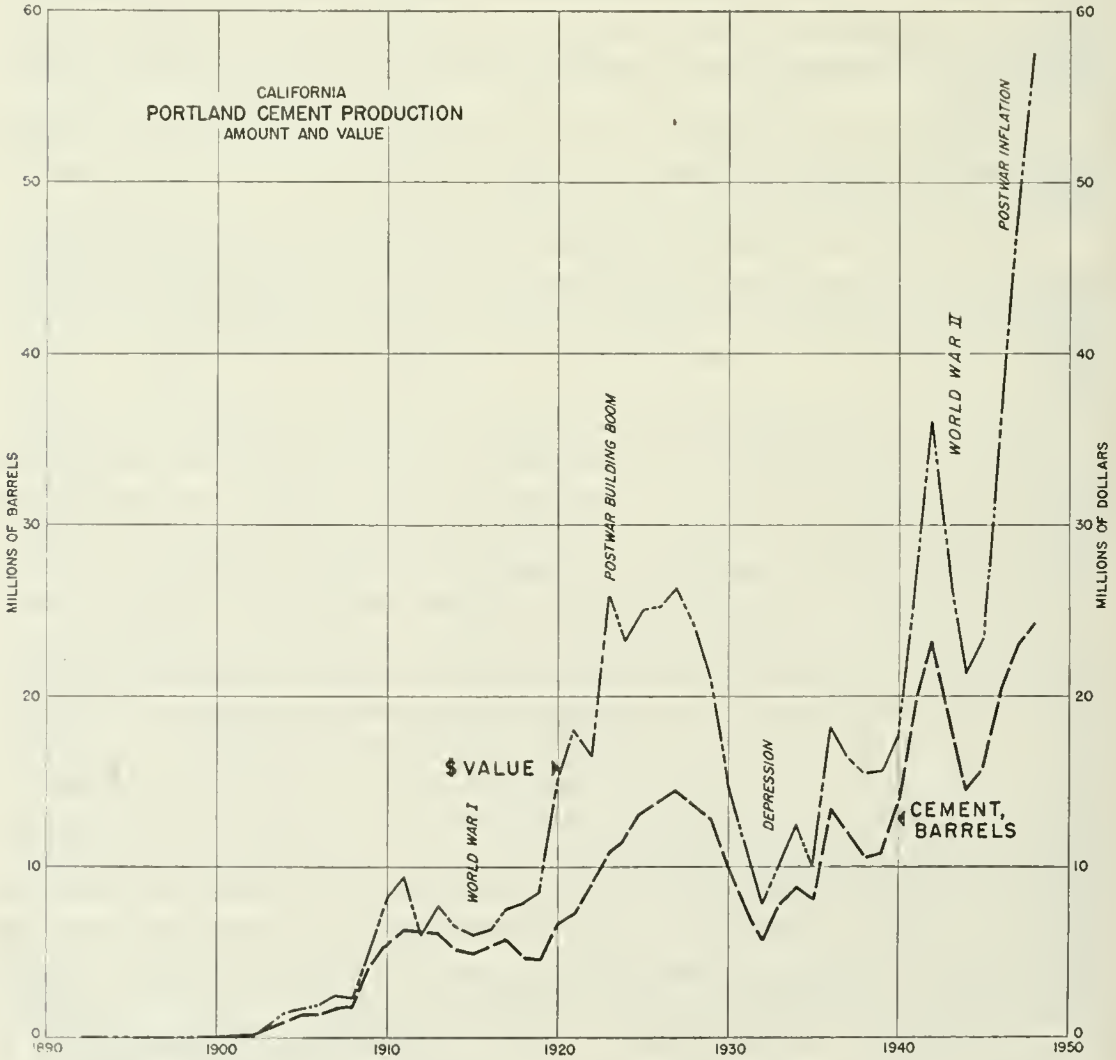

FIGURE 1. Chart showing amount and value of portland cement produced in California, 1892-1948.

of high-calcium limestone located about 28 miles from Thorne on the Santa Fe Railroad.

Utilization and Markets. Since 1891, when portland cement production began in California, by far the largest proportion of this production has been marketed and used in the state; in 1948 less than 15 percent was shipped out of California. As portland cement is primarily a construction material, its production and marketing have been governed largely by building booms brought about by housing demands and by expanded wartime industry and military construction. California's expanded road-building program and vastly increased oil exploration have also consumed large quantities of cement. These demands have raised California to a position second only to Pennsylvania as a cement-producing state.

Being a low-cost product, cement is generally produced as close to centers of population as the availability of raw materials will permit. Five cement plants are located within a radius of 125 miles of San Francisco, and six within a similar distance of Los Angeles.

The average mill price of portland cement in California in 1947 was $2.04 per barrel of 376 pounds. The national average was $1.90 per barrel. In 1948, however, the California average showed $2.04 per barrel as against $2.39 for the country at large.

World War II production was channeled into a small number of cement types; since the war, the trend has been toward more varieties and more specialized types.

History of Production. Production of portland cement in California began in 1891 on the Jamul Ranch in San Diego County.[5] A plant with 150 barrels per day capacity was put into operation by the Jamul interests. Beginning in 1859 and prior to 1891, there had been a considerable production of natural hydraulic cement.[6]

Natural cement differs from portland cement in that it is burned from natural cement-rock (argillaceous limestone) at temperatures obtainable in an ordinary lime kiln without any pre-mixing or pulverizing of the raw materials. By 1865, San Francisco was consuming 100,000 barrels of natural cement yearly. Owing to foreign competition from low-cost products shipped by water, production of portland cement increased very slowly through the nineties. An increase from 5,000 barrels to 52,000 barrels per year was recorded during that period. From 1902, production increased rapidly and many plants were put into operation throughout the state. Between 1902 and the pre-war slump of 1912-16, production increased from 171,000 to 6,371,369 barrels. A new high of 24,162,926 barrels was recorded during 1948, and production is still increasing.

Salient events in the portland cement industry.

1891—First production at Jamul, San Diego County (the Jamul product is classed by some as a natural cement).

1894—Opening of plant of California Portland Cement Company at Colton, San Bernardino County.

1902-3—Establishment of two plants, one in Napa County by the Standard Portland Cement Company, and one in Solano County, near Fairfield, by the Pacific Portland Cement Company.

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[5] Storms, W. H., San Diego County: California Min. Bur. Rept. 11, p. 383, 1892.

[6] Symons, H. H., California mineral production for 1945: California Div. Mines Bull. 137, p. 73, 1946.

1906—Establishment of the plant at Davenport, Santa Cruz County, by the Standard Portland Cement Company (later operated by Santa Cruz Portland Cement Company).

1908—First shipments made from Henry Cowell Lime and Cement Company plant at Cowell, Contra Costa County.

1909—Plant of Riverside Portland Cement Company, erected at Crestmore near Riverside, Riverside County; also, a plant at Monlith, Kern County, was erected by the City of Los Angeles (now operated by Monolith Portland Cement Company).

1910—The Golden State Portland Cement Company began producing at Oro Grande (later taken over by Riverside Cement Company).

1913—Erection of Old Mission Portland Cement Company plant at San Juan Bautista, San Benito County, which began operating in 1918 (now owned by Pacific Portland Cement Company).

1916—Establishment of plant of Southwestern Portland Cement Company, at Victorville, San Bernardino County.

1924—Opening of Pacific Portland Cement Company plant at Redwood City, San Mateo County.

1925—Yosemite Portland Cement Corporation built plant at Merced, Merced County.

1926—Calaveras Cement Company plant opened at San Andreas, Calaveras County.

1940—Establishment of Permanente Cement Company plant at Permanente, Santa Clara County.

Portland cement production has been recorded from Calaveras, Contra Costa, Kern, Los Angeles, Merced, Riverside, Santa Barbara, San Benito, San Bernardino, San Diego, San Mateo, Santa Clara, Santa Cruz, and Solano Counties, a total of fourteen. At the present time cement mills are active only in Calaveras, Kern, Los Angeles, Riverside, San Bernardino, San Mateo, Santa Clara, and Santa Cruz Counties, a total of eight.

CLAYS

By Mort D. Turner

Clay deposits in California not only form the basis of a large and growing ceramic industry, but certain types also function usefully as oil-well drilling muds; filtering agents for mineral, vegetable, and animal oils; insecticide carriers; and as fillers. The state's most notably deficiency in this field is that of ball clay.

During 1948 California yielded 2,673,877 tons of clay of all types, a marked increase over the 1,950,076 tons produced in 1947. The 1948 production from the state represented 7.1 percent of the total quantity and 4.5 percent of the total value of the clay produced in the United States for the same year. Of the total United States production in 1948, California mined 5.6 percent of the fire clay, 1.6 percent of the kaolin or china clay, and 8.4 percent of the miscellaneous clays.[1]

General Geology and Classification of Clays. Clay is commonly classified in three basic ways, according to (1) its mineralogic characteristics, (2) its geological occurrence and origin, or (3) its industrial uses.

The clay minerals are of three major mineralogic groups, the kaolins, the montmorillonites, and the illites. The kaolin minerals [2] are kaolinite,

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[1] Josephson, G. W. and Linn, A., Clays: Minerals Yearbook 1946, pp. 247-263, 1948.

[2] Ross, C. S., and Kerr, P. F., The kaolin minerals: U. S. Geol. Survey Prof. Paper 165, pp. 151-180, 1931.

Ross, C. S., and Kerr, P. F., Halloysite and allophane: U. S. Geol. Survey Prof. Paper 185-G, pp. 135-148, 1934.

dickite, halloysite, and nacrite, all of which have the ideal formula $Al_2Si_2O_5(OH)_4$. They are distinguished by their internal crystalline structure. Kaolinite is almost always the dominant mineral in commercial ceramic clay deposits.

Minerals of the montmorillonite group[3] are montmorillonite (hydrous magnesium aluminum silicate), saponite (hydrous magnesium aluminum silicate), hectorite (hydrous magnesium lithium silicate), biedellite (hydrous aluminum silicate), and nontronite (hydrous iron aluminum silicate). These minerals may vary in composition principally by the exchange of sodium and calcium for other elements normally present.

The illite clays are potash-bearing, micaceous, and highly complex in their molecular structure. The general formula as given by Grim[4] is $(OH)_4K_y(Al_4 \cdot Fe_4 \cdot Mg_4 \cdot Mg_6)\ (Si_{8-y} \cdot Al_y)O_{20}$. Illite is widespread as a constituent of soils but no deposits of the mineral are known which are important commercially.

Clays are divisible into two main geological groups; residual (formed in their present position), and sedimentary (transported to their present position from a point of origin elsewhere). Most residual clays are formed by the weathering of materials at or near the surface or, less commonly, by alteration of rock by hot rising mineralized water. The sedimentary clays are derived from residual clays by erosion, usually by running water.

Commercial clays are of six general types: (1) fire clay, (2) china clay, (3) ball clay, (4) bentonite, (5) fuller's earth, and (6) miscellaneous clays. The kaolin-group minerals are the principal constituents of the fire clay, china clay, ball clay, and miscellaneous clays. These clays differ only in impurities present. China clay is white-firing, and is used in the manufacture of whiteware, refractories, and as a filler in paint, rubber, and paper. Ball clay is white-burning, has a very high plasticity, and is used primarily in whiteware mixes with china clay. Fire clay is refractory and lacks the white-firing properties of china clay and the plasticity of ball clay; it is used in the manufacture of refractories and heavy clay products.

Most miscellaneous clays are red-burning, non-refractory alluvial materials. They are used in the manufacture of building brick and other heavy clay products. A large volume of miscellaneous clay is also used as a source of silica and alumina in the manufacture of portland cement. Miscellaneous clays include rotary drilling mud, large quantities of which are produced in California.

Bentonite and fuller's earth are composed largely of the montmorillonite-group minerals. Swelling or gel-forming bentonites absorb many times their own weight in water, as distinguished from non-swelling bentonites. Both are highly plastic, very fine-grained clays. Fuller's earth differs from the bentonites by being nonswelling and nearly nonplastic. The gel-forming bentonites are used as a suspending agent in well-drilling mud and as a binder in foundry sand. Nonswelling bentonite and fullers earth are used primarily as filtering and decolorizing agents for oils.

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[3] Ross, C. S., and Hendricks, S. B., Minerals of the montmorillonite group, their origin and relation to soils and clays: U. S. Geol. Survey Prof. Paper 205B, pp. 64-67, 1945.

Davis, C. W., Vacher, H. C., and Conley, J. E., Bentonite—its properties, mining, preparation, and utilization: U. S. Bur. Mines Tech. Paper 609, pp. 3-4, 1940.

[4] Grim, R. E., Relation of the composition to the properties of clays: Am. Ceramic Soc, Jour., vol. 22, pp. 141-151, 1939.

Fire Clays. Fire clay, china clay, and ball clay are the most refractory of the commercial clays. Fire clays are considered to be those clays with a P.C.E. of 19 or greater.[5] Clays with high P.C.E. values are high in alumina and silica and low in such impurities as ferric oxide, lime, and magnesia. The impurities act as fluxes, causing the clay to soften and melt at a lower temperature. Fire clay is composed largely of the kaolin group of clay minerals, but generally contains some iron oxide and free silica. Fired color may range from near-white to red.

California has relatively large deposits of high-quality, cheaply minable refractory clays of P.C.E. 19 to 32. Super-duty clays of P.C.E. 33 to 35 are restricted to the Ione, Alberhill, and Tesla areas, where there are rather limited reserves.

Most of the high-grade fire clays of California are in sedimentary deposits formed in the Paleocene and Eocene epochs. At this time topography was subdued, a large part of the state was covered by shallow seas, and a warm, moist climate prevailed. These conditions caused deep weathering of the land surface and led to the formation of residual clay over large areas of granitic and metamorphic rocks. The clays were gradually eroded and deposited in lagoons and deltas. Beds that contain clay deposits of commercial interest are exposed in (1) a narrow, discontinuous belt along the western Sierra Nevada foothills; (2) a horseshoe shaped belt on the west, north, and east sides of the northern portion of the Santa Ana Mountains, Riverside and Orange Counties; and (3) an area in the northern portion of the Diablo Range, Alameda and Contra Costa Counties. The important production centers are at Alberhill in Riverside County, Ione in Amador County, and Lincoln in Placer County.

Fire-clay deposits of the Sierran foothills are contained in the Ione formation [6] which formed in the shallow sea that bordered the western flank of the ancestral Sierra Nevada. The clay bodies are lenticular and nearly horizontal. Some of the clay-bearing beds have been capped and preserved from erosion by volcanic rock, principally rhyolite and andesite. Such cappings are common in the Lincoln area. Refractory clays occur throughout the belt and are produced commercially at the following localities: Lincoln, Placer County; Michigan Bar and Folsom, Sacramento County; Ione, Amador County; Valley Springs and Knights Ferry, Calaveras County; and near Cooperstown, Tuolumne County.

In the Santa Ana Mountain area near Alberhill,[7] where a Paleocene sea extended into the area now occupied by Santa Ana and Temescal Canyons, clays were also extensively deposited. The clay-bearing sediments in this area are in a unit known as the Martinez formation to some geologists and as the Silverado formation to others.

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[5] P.C.E. (pyrometric cone equivalent) is a means of designating the refractoriness of a clay by comparison, during firing, to the behavior of a standard set of prepared pyrometric cones. The number is that of the standard pyrometric cone whose tip touches the support simultaneously with the tip of a cone of the refractory material being tested. The testing is done under standardized conditions.

[6] Allen, V. T., The Ione formation of California: Univ. California Dept. Geol. Sci. Bull., vol. 18, pp. 354-359, 363-365, 1929.

Dietrich, W. F., The clay resources and the ceramic industry of California: California Div. Mines and Mining Bull. 99, pp. 49-63, 146-158, 1928.

Bates, T. F., Origin of the Edwin clay, Ione, California: Geol. Soc. America Bull., vol. 56, pp. 1-38, 1945.

[7] Engel, René, Economic map of the Lake Elsinore quadrangle, California Div. Mines, 1949.

Hill, J. H., Clay deposits of the Alberhill Coal and Clay Company: California Min. Bur. Rept. 19, pp. 185-210, 1923.

Dietrich, W. F., op. cit., pp. 161-182.

These beds are, in general, more highly deformed than those of the Ione formation. They are, therefore, more difficult to explore and mine. Most of the commercial deposits are in Temescal Canyon, between Corona and Lake Elsinore, and in the north end of the Santa Ana Mountains, southwest of Corona.

The fire clay of the northern Diablo Range is in Eocene beds,[8] which, in the Diablo and Tesla coal districts, yielded some of the first fire clays mined in California.[9] Small amounts of super-duty clay have been mined in recent years at Tesla and may be present in other parts of the district. These clays are composed of material which apparently originated in the Sierra Nevada and may have been deposited contemporaneously with the Ione formation.[10]

Although a large part of the California fire clay is used for the manufacture of refractory products such as fire brick, ladle brick, and fire-clay mortar, much is also used in drain tile, sewer pipe, face tile, pottery, and high-grade tile. Plants using fire clay are located in the San Francisco and Los Angeles areas; at Lincoln, Placer County, Ione, Amador County, Pittsburg, Contra Costa County, and Sacramento. California is relatively self-sufficient in fire clay. Almost none is shipped into the state in crude form, but significant amounts of manufactured refractory clay products are imported from the east and middle west. California also supplies a large part of the refractory clay used in the neighboring states.

In 1948 the output of fire clay from California was 547,330 tons, of which 35 percent was obtained from the Ione area. From 1945-48 the average price of fire clay in the United States rose from $2.52 to $3.00 per ton. In 1948 fire clay produced in California had an average value of $2.40 per ton.

China Clay or Kaolin. China clay, although highly refractory, differs from the lower-grade fire clays in having a dead-white raw and fired color, and, in most cases, a low plasticity. Four areas in California are currently yielding china clay. A clay-sand mixture is obtained from beds of the Paleocene Silverado formation [11] on the west side of the Santa Ana Mountains. The clay and sand fractions are separated by washing, and both are marketed. Two plants in the vicinity of Trabuco Canyon, east of El Toro in Orange County, are treating this material. Residual kaolin, derived from the alteration of acidic volcanic rock, is being mined at Jawbone Canyon, Kern County; Hart Mountain, San Bernardino County; and in Little Antelope Valley, southern Mono County. China clay was produced in the past at Ione, where, as at Trabuco Canyon, the clay was recovered by washing a kaolin-sand mixture.

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[8] Huey, A. S., Geology of the Tesla qaudrangle, California: California Div. Mines Bull. 140, pp. 33-38, 60, 1948.

Dietrich, W. F., op. cit., pp. 42-46.

Allen, V. T., Eocene anauxite clays and sands in the Coast Ranges in California: Geol. Soc. America Bull., vol. 52, pp. 271-294, 1941.

[9] Cronise, T. F., The natural wealth of California, p. 629, 1868.

[10] Stewart, Ralph, Lower Tertiary stratigraphy of Mount Diablo, Marysville Butte, and west-central border of lower Central Valley of California: U. S. Geol. Survey Oil and Gas Inv., Prelim. Chart 34, 2 sheets, 1949.

[11] Woodring, W. P., and Popenoe, W. P., Paleocene and Eocene stratigraphy of the northwestern Santa Ana Mountains, Orange County, California: U. S. Geol. Survey Oil and Gas Inv., Prelim. Chart 12, 1945.

Stauffer, C. R., High-alumina clays of the Santa Ana Mountain region, California: U. S. Geol. Survey Strategic Minerals Investigations, Preliminary Map 3-197, 1945.

The Trabuco product is consumed largely in pottery manufacture. The clay from Hart Mountain is used almost entirely in high-grade tile, and Little Antelope Valley clay has been marketed largely as paper and rubber filler. Large amounts of china clay are also shipped into California from the southeastern states and England.

Top-quality china clay commands the highest price of any clay in common use in California. It is generally expensive to process, and the costs of bringing the material into the state are high. During 1948 the average value of kaolin produced in California was $13.80 per short ton, as against $12.60 for the national average; each is figured exclusive of shipping charges. In that year California produced 25,562 tons—a significant increase over the 16,359 tons produced during 1947.

Ball Clay. No ball clay has been produced in California, and almost the entire amount consumed in the state is brought from Kentucky and Tennessee. For certain applications in which a pale-buff color is acceptable, plastic clays from the Ione, Lincoln, and Alberhill areas are used in place of ball clay in California.

Bentonite. Bentonites are derived from the alteration of vitric tuffs, usually after deposition in bodies of water. In a few places percolating ground water has apparently altered landlaid pyroclastics in the same way. This appears to have been the origin of a deposit at Kearsarge, Inyo County, which is interbedded with Recent coarse alluvial-fan material. The bentonite deposits in California are ordinarily in gently dipping beds, and range from a few inches to several feet in thickness.

California has relatively large reserves of non-swelling bentonite, and at the following localities deposits are now being worked: the Otay Valley, San Diego County; an area 8 miles north of Johannesburg in San Bernardino County; Tres Pinos, San Benito County; an area along the Amargosa River near Tecopa and Shoshone, Inyo County; and at Kearsarge, Inyo County. Currently idle deposits include one at Boron, Kern County, and several in San Bernardino County. Large quantities of non-swelling bentonite are used in California in the clarification and decolorizing of mineral, vegetable, and animal oils and fats; as fillers in various products; and as carriers for insecticides.

Deposits of the gel-forming (swelling) types are limited in California, and large quantities of these clays are brought in from Wyoming and South Dakota. A deposit of the swelling variety, mined near Hector, San Bernardino County, is composed of the montmorillonite mineral hectorite; another deposit of swelling bentonite is located 5 miles north of Randsburg, Kern County.

The ability to absorb and retain water to a degree unknown in other materials makes swelling bentonite useful in many ways. Its principal use is in oil-well drilling fluids, where it serves as a suspending agent both for the drill cuttings, and for such heavy components of the drill fluid as barite. It is used as a seal for dams and ditches, and as a binder in foundry sand; it also has many other applications. The petroleum industry of California is the second largest user of bentonitic clay in the United States. Wyoming and South Dakota are the largest producers. During 1948, there was produced in California 18,676 tons of bentonite valued at $101,450.

Bentonite is usually sold crushed, and is frequently bagged. From 1945-48 the average national price for all bentonite rose from $6.57 to $7.74 per ton. The average price in California for 1948 was $5.38 per ton.

Fuller's Earth. Fuller's earth is similar in many respects to nonswelling bentonite in that both are composed largely of montmorillonite-group minerals and both are used as agents in the decolorizing and deodorizing of oils and fats. Fuller's earth probably originates from the alteration of bentonite after burial and differs from it in being less plastic.

Only one deposit of fuller's earth, that near Olancha, Inyo County, is being actively mined in California. Several idle deposits in Kern and San Bernardino Counties are also classified as fuller's earth; one near Tehachapi has been an important producer in the past.[12]

The Olancha product, a plastic variety, is used primarily for the decolorizing and deodorizing of animal, fish, and vegetable oils; fatty acids, and sugar solutions; and for the decolorizing of waxes, resins, and petroleum oils. For some of these uses, fuller's earth is acceptable in the natural state, whereas for others it has to be treated by acid, a process called activation. This process increases the efficiency of the decolorizing and deodorizing action. An important use for non-plastic types of fuller's earth which has recently been developed is as an absorbent for oil and grease on factory floors. This application consumed 19 percent of the national production of fuller's earth in 1948. Almost no fuller's earth is imported into the United States, but more than 17,000 tons were exported in 1947.

The average value for all fuller's earth produced in the United States during 1948 was $15.43 per ton, as compared with a value of $12.38 for 1946. In 1948, fuller's earth from Georgia and Florida comprised 55 percent of the national total, and that from Texas 27 percent of the total.

Miscellaneous Clay. Of California's annual clay output, three-quarters is classified as ''miscellaneous'' or ''common.'' While most of the miscellaneous clays are obtained from Recent alluvium in river flood plains, some are mined from large residual deposits. Almost every county in California has produced miscellaneous clay in the past, but in recent years the most actively worked deposits were those near large industrial centers. Improved transportation facilities and mass-production techniques have forced the abandonment of many outlying deposits. In 1948 miscellaneous-type clays were produced in 23 counties. Los Angeles County had the largest output.

Rotary drilling mud is produced from the dry lake beds of the Mojave Desert region, mostly centered around Muroc and Rosamond, Kern County. Nearly every cement plant has an immediately adjoining clay pit for its own needs, and all large cities have brick yards with nearby clay pits.

Valley alluvium is commonly used for common brick and tile. Proximity to areas of consumption rather than quality has been the principal factor. Rotary drilling muds have more exacting specifications: high weight, low sand content, and low water loss are desirable. Drilling muds are generally sold ground and bagged, and are mixed with bentonite and chemicals at the well. The clay material used in cement manufacture is generally shale, weathered slate, or weathered volcanic rock, rather than pure clay.

Of the miscellaneous clay produced in California in 1947, heavy clay products such as common brick, face brick, paving brick, drain tile,

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[12] Kerr, P. F., and Cameron, E. N., Fuller's earth of bentonitic origin from Tehachapi, California: Am. Mineralogist, vol. 21, no. 4, pp. 230-237, 1936.

sewer pipe, and other similar products absorbed 73 percent; 24 percent was used in the manufacture of cement; and the remaining 3 percent was used in pottery, tile, rubber filler, foundry work, and rotary drilling muds.

Miscellaneous clays totaling 2,082,309 tons, valued at $2,046,911, were produced in California during 1948. Prices for miscellaneous clay are the lowest among the various clays. The average price for miscellaneous clay produced in California in 1948 was $0.97 per ton, which included the more valuable rotary drilling mud. The national average in 1948 was $0.83 per ton. Some of the special types listed under this heading, however, sell for more than $10.00 per ton.

Mining Methods and Treatment. As clays are high-tonnage low-cost materials, they are usually mined by open pit rather than underground methods. Underground methods are used only on extensive bodies of high-quality clay with thick overburdens. In California, underground mining is employed at the Edwin mine near Ione, Amador County, where highly refractory clay is mined, and at the Olancha fuller's earth mine. During recent years, increased cost of timber and equipment has not been offset by the rise in value of the clay. This has forced the temporary

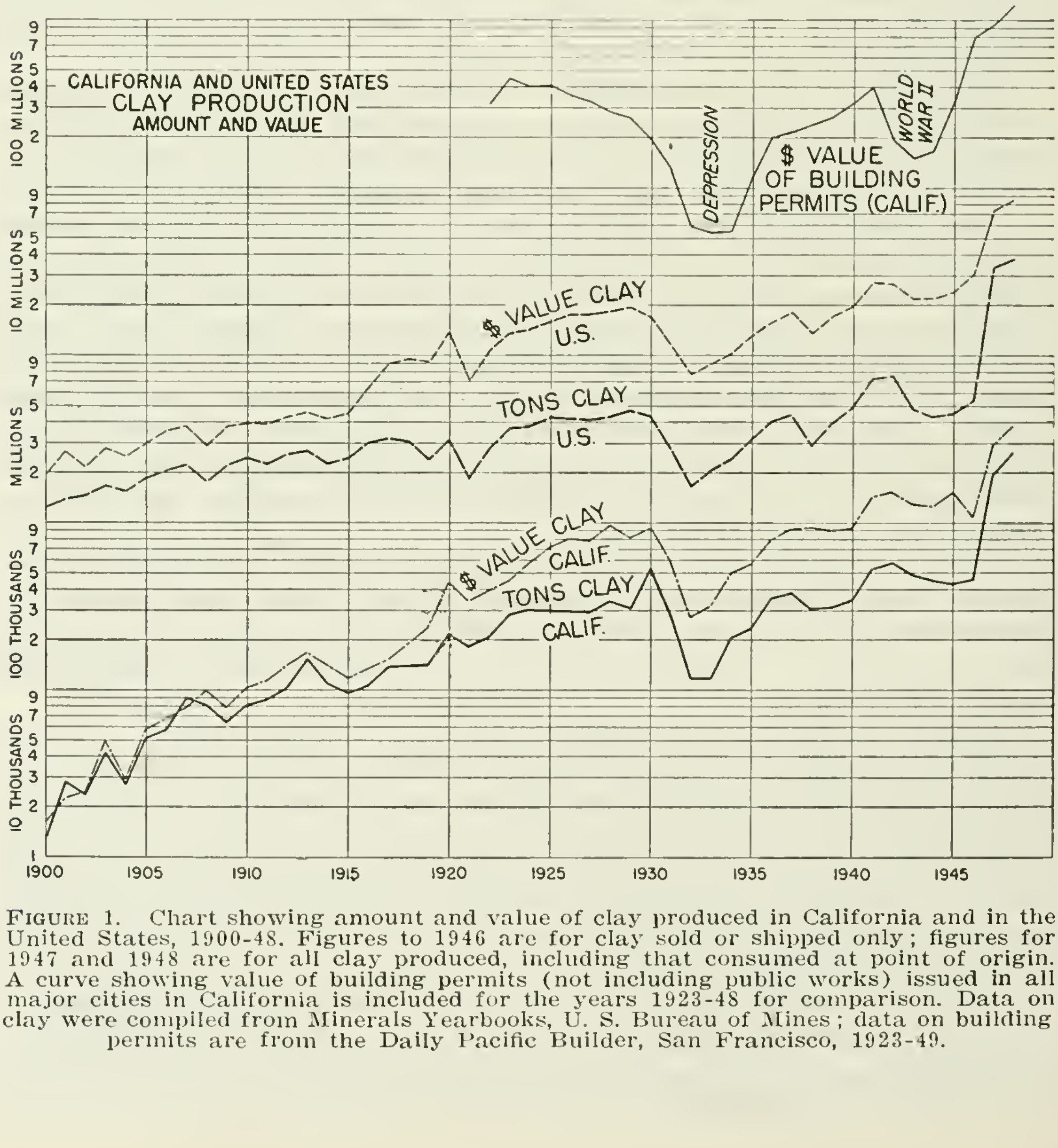

FIGURE 1. Chart showing amount and value of clay produced in California and in the United States, 1900-48. Figures to 1946 are for clay sold or shipped only; figures for 1947 and 1948 are for all clay produced, including that consumed at point of origin. A curve showing value of building permits (not including public works) issued in all major cities in California is included for the years 1923-48 for comparison. Data on clay were compiled from Minerals Yearbooks, U. S. Bureau of Mines; data on building permits are from the Daily Pacific Builder, San Francisco, 1923-49.

*Clay sold or used by producers in California during 1948, by counties.** [1]

County	Kaolin		Fire clay		Bentonite		Miscellaneous clay		Total	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
Alameda							14,404	$16,109	14,404	$16,109
Amador			189,884	$625,537					189,884	625,537
Calaveras, Contra Costa, Fresno, and Humboldt							211,650	163,539	211,650	163,539
Inyo					[2]	[2]			[2]	[2]
Kern	[2]	[2]	[2]	[2]			209,803	667,798	215,953	768,280
Los Angeles							491,167	368,781	491,167	368,781
Marin							[2]	[2]	[2]	[2]
Orange	[2]	[2]	[2]	[2]			[2]	[2]	19,292	74,984
Placer			[2]	[2]			[2]	[2]	[2]	[2]
Riverside			121,579	352,064			218,417	210,180	339,996	562,244
Sacramento			[2]	[2]			[2]	[2]	23,495	[2]
San Benito					[2]	[2]			[2]	[2]
San Bernardino	[2]	[2]			[2]	[2]	141,838	122,139	165,303	386,355
San Diego					[2]	[2]	[2]	[2]	35,222	60,922
San Joaquin							18,184	14,259	18,184	14,259
San Luis Obispo, San Mateo, and Santa Barbara							326,080	164,283	326,080	164,283
Santa Clara			[2]	[2]			[2]	[2]	177,780	[2]
Santa Cruz							[2]	[2]	[2]	[2]
Stanislaus			[2]	[2]					[2]	[2]
Sutter, Tulare, and Ventura							110,965	111,923	110,965	111,923
Undistributed [2]	25,562	$352,538	235,867	334,829	18,676	$101,450	339,801	207,897	334,502	496,110
Totals	25,562	$352,538	547,330	$1,312,430	18,676	$101,450	2,082,309	$2,046,911	2,673,877	$3,813,329

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* These figures are furnished by the United States Bureau of Mines in cooperation with the California State Division of Mines.

[1] Exclusive of fuller's earth (produced in Inyo County).

[2] Figures that may not be shown separately are combined as "Undistributed."

or permanent closing of many underground clay workings. Power digging and loading is now almost universally used. Blasting is sometimes also employed. Many operators, especially in California, selectively bench different clays in the same pit. Others bench only to remove overburden and mine the entire clay body on a single face. The amount of overburden that can be removed economically depends upon the value and thickness of the clay. In California clay deposits, the ratio of the thickness of overburden removed to thickness of clay mined is as high as 7.5 to 1.

Almost all clay is ground before use; some, such as the kaolin near El Toro, requires beneficiation. Frequently the grinding is done by the producer, but more often by the manufacturer. Most clays are used in combination with other clays to give the desired physical characteristics to the finished product. This mixing is generally done by the user. Except where the user is located at or near the point of supply, the cost of mining is nearly always less than the shipping costs.

DIATOMITE

By Gordon B. Oakeshott

The use of diatomite (diatomaceous earth) for filtration, in fillers, and for insulation, has been increasing rapidly in the past few years. California is by far the largest diatomite-producing state and contains the world's largest diatomite quarry near Lompoc in Santa Barbara County.

Geologic Occurrence. Diatomite is a light-colored, light-weight sedimentary rock composed largely of the microscopic tests of diatoms, which are silica-secreting single-celled plants. More than 200 species of this minute plant are known, but disc-shaped and needle-shaped forms are most common. Radiolaria and silicoflagellates are other common silica-secreting organisms found in diatomite. Sponge spicules are also common. The marine diatomaceous shales of the upper Miocene in California are notable also for perfectly preserved fossil fishes; in some places shark teeth, whale bones, and fossil birds are common. Impure varieties of diatomite contain clay, silt, fine sand, limestone, thin beds of volcanic ash, and hard silica rocks including chert, opal, and porcelaneous chert materials. Every gradation is found, from pure diatomite through diatomaceous shale into clay shales and siltstones, all containing various proportions of diatoms. Some varieties of diatomite are calcareous and contain foraminifera.

Quarry operators recognize three types of diatomite—pure thinly-stratified, impure coarsely stratified, and impure massive. Lenses, nodules, and layers of porcelaneous silica rocks, and opaline and chalcedonic cherts are common in even the purer forms. Numerous phosphatic nodules or pellets and thin beds of silvery volcanic ash also occur. Geologists have noted that many diatomaceous beds grade laterally into chert beds, and also grade into coarse clastic sediments. It is now known that diatomaceous rocks, such as those of the upper Miocene Monterey formation in California, are of shallow-water origin. These rocks formed with clastic sediments under conditions that allowed diatom tests to accumulate in greater volume than the clastic material. Bramlette[1] has recently dis-

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[1] Bramlette, M. N., The Monterey formation of California and the origin of its siliceous rocks: U. S. Geol. Survey Prof. Paper 212, 1946.

cussed fully the origin of diatomite and other siliceous rocks of the Monterey formation. He believes that the silica needed to form the large quantities of diatoms had its source in the finely divided particles of volcanic ash so universally found in association with beds of both marine and fresh-water diatomite.

In California there are two potentially commercial modes of occurrence of diatomite: (1) the marine upper Miocene Monterey formation, and its equivalents by other names, and (2) fresh-water lake beds of Tertiary to Recent age. The first is by far the more important, accounting for nearly all diatomite production. The Monterey formation is widely exposed throughout the Coast Ranges from Point Arena in Mendocino County southward to San Onofre in San Diego County, and extending eastward into the San Joaquin Valley. Thicknesses of high-quality diatomite up to 1000 feet occur in the Santa Maria Basin and Santa Ynez Mountains in Santa Barbara County. In that area, and some others, diatomite extends upward from the upper Miocene beds into beds of the lower Pliocene epoch, but that of commercial grade seems to be upper Miocene. Numerous fresh-water beds of diatomite have been found in lake beds of Tertiary to Recent age in association with volcanic rocks of eastern and northern California.

Principal Deposits. Deposits of diatomite have been found in many counties, and some effort toward commercial production has been made in Contra Costa, Fresno, Inyo, Kern, Monterey, Orange, Plumas, San Benito, San Bernardino, San Joaquin, San Luis Obispo, Shasta, Sonoma, and Tehama Counties. Of the five producers listed for the state in 1947, one was at Zurich in Inyo County, one at San Pedro in Los Angeles County, one at Tionesta in Modoc County, and one each at Lompoc and Solvang in Santa Barbara County.

The geology of the extensive diatomite deposits in the southern part of the Santa Maria Basin in Santa Barbara County has recently been described by Dibblee[2] and shown in detail on the geologic maps, scale 1:62500, accompanying his report. Most of the diatomite deposits are in marine beds of the Sisquoc formation of upper Miocene and lower Pliocene age, though diatomite is locally interbedded with shale and chert of the upper part of the Monterey formation. All of the commercially developed deposits are in the lower part (probably upper Miocene) of the Sisquoc formation, the upper part of that formation containing less-pure massive diatomite of no present value. One of these, south of Lompoc Valley in the northern foothills of the Santa Ynez Mountains, is the largest known diatomite deposit in the world. It was first worked in the eighties, and for many years has been operated by Johns-Manville Products Corporation. The commercial deposit consists of 1000 feet of pure, thinly stratified diatomite belonging to the lower part of the Sisquoc formation, and covers an area of 17 square miles. The diatomite here has been preserved in synclines, where it is quarried. The best-grade diatomite is thinly stratified, with laminae averaging about $\frac{1}{32}$-inch in thickness. It is cream-colored below the surface and dries to a pure white. As quarried, it contains about 50 percent water; however, it holds 75 percent at saturation. The pure air-dried diatomite has a density of approximately 0.5.

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[2] Dibblee, T. W., Jr., Geology of southwestern Santa Barbara County, California: California Div. Mines Bull. 150, in press.

A small deposit of high-grade diatomite, operated by H. M. Johnson, is exposed in a sharp syncline and anticline one mile northwest of Solvang.

The Dicalite Division of Great Lakes Carbon Corporation has developed a large, high-quality deposit on the property of W. C. H. Dibblee 7 miles southeast of Lompoc. The deposit is of lower Sisquoc age and is exposed over 1500 acres; estimated reserve is 166,000,000 cubic yards. Structurally, the deposit lies in a local basin 2 miles long, which includes three synclines and two anticlines striking generally N. 85° W.; dips range from horizontal to 50°.

The second largest commercial deposit of diatomite in California is on the north side of the Palos Verdes hills, near Walteria, in Los Angeles County. This deposit is operated by the Dicalite Division of the Great Lakes Carbon Corporation. Here diatomite, diatomaceous shale, and diatomaceous mudstone beds are part of the upper Miocene Valmonte

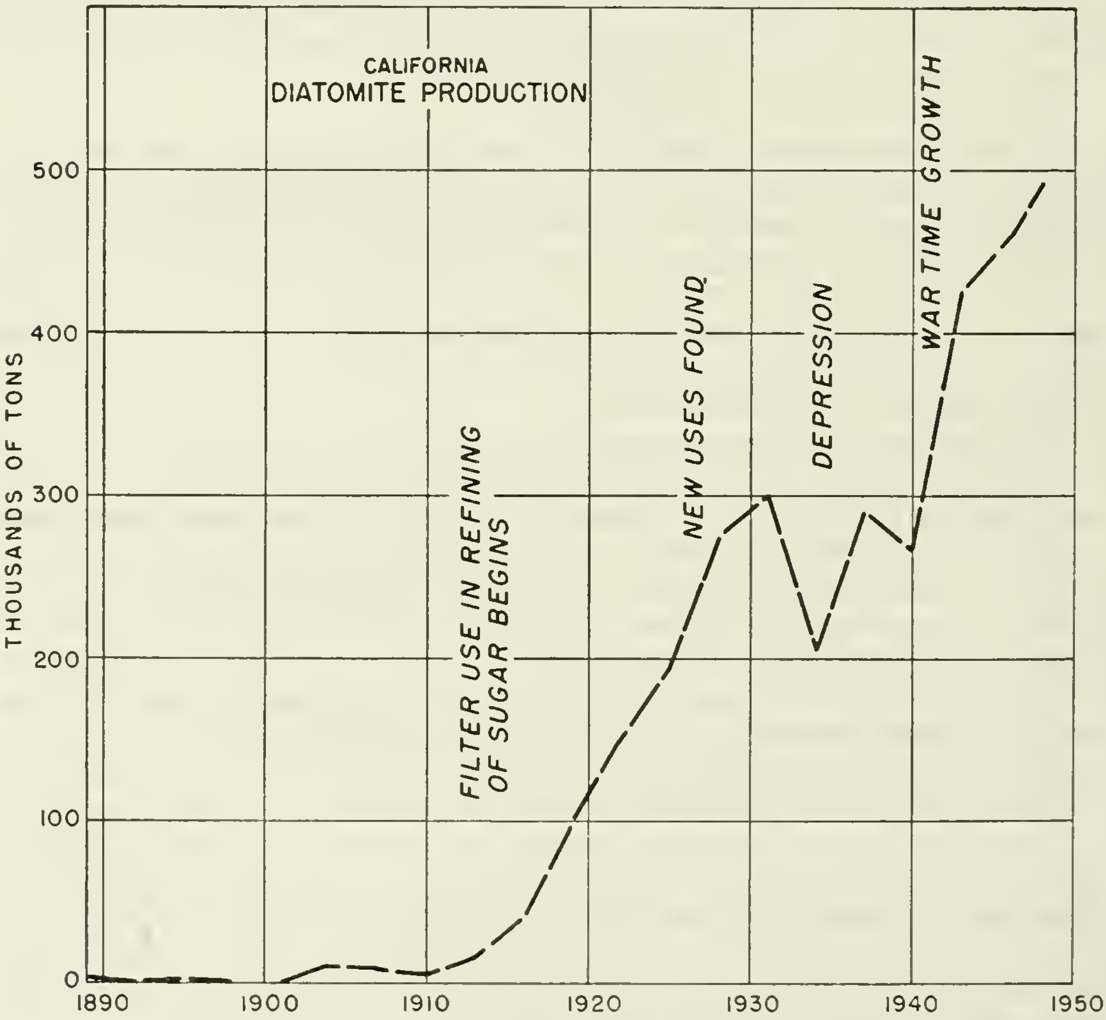

FIGURE 1. Chart showing diatomite production in California, 1889-1948; curve derived from 3-year averages.

formation. The beds are folded to form a series of minor anticlines and synclines and are faulted along the north side of the deposit. Woodring, Bramlette, and Kew [3] mapped the distribution of the Valmonte diatomite in a study of the geology of the Palos Verdes Hills.

A deposit of diatomite near Bradley in southern Monterey County has recently been acquired by the Dicalite Division of the Great Lakes Carbon Corporation. The beds are several hundred feet thick and extend northwest for more than 40 miles, from a point 5 miles northwest of Bradley. The diatomite is in the upper part of the Monterey formation and is underlain by porcelaneous rocks and chert.

Among the many smaller deposits with possibilities of further commercial development are (1) the Monterey diatomite just west of Pinole in Contra Costa County; (2) fresh-water diatomite in Tertiary lake beds near Zurich in Inyo County; (3) extensive beds of fresh-water diatomite intercalated with recent lava flows along the Pit River and Hat Creek; (4) lake-deposited late Tertiary (?) diatomite beds 20 to 30 feet thick on Paoha Island in Mono Lake in Mono County; and (5) fresh-water deposits operated by H. W. Free at Tionesta in Modoc County.

Utilization. Uses of diatomite have been increasing steadily for the past several years. These are grouped under four headings, in order, with the proportions indicated as follows: (1) filters, more than $\frac{1}{2}$; (2) fillers, $\frac{1}{5}$; (3) insulation, $\frac{1}{8}$; and (4) lightweight aggregate and abrasive. Filters for all types of liquids are now made, in several varieties for the various specific purposes. Powdered diatomite is used in fillers and admixtures where a chemically inert lightweight mineral is needed. Insulation products include natural saw brick, dried at temperatures up to 500°F., and manufactured pressed brick, which is made both from a simple aggregate and from aggregate containing a binder. Natural aggregate and calcined aggregate are also made and sacked. As an abrasive, diatomite is used chiefly for metal polishes and dental powders; but the total volume so used is insignificant when compared with the other uses.

It is probable that diatomaceous deposits have been indirectly of enormous importance in the formation of petroleum in California. It is known that the organic matter of diatoms has formed hydrocarbons, and most geologists believe that diatomaceous shales may well have been a major source rock of petroleum.

Large deposits of oil-saturated shale of the Sisquoc formation (upper Miocene-lower Pliocene) crop out in the Santa Ynez Mountains and Casmalia Hills. Some properties near Casmalia have been operated, with distillation plants producing 30 to 35 gallons of crude oil per ton of oil shale. In the same region, one operator is burning the oil-saturated diatomite to form a tough, lightweight aggregate.

Mining operations. A complete account of the operation of the Johns-Manville Products Corporation near Lompoc has been given by Mulryan.[4] The report includes photomicrographs of diatoms and their description. There are extensive underground workings at the deposit, including a main tunnel more than 7000 feet long. Large shafts carry

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[3] Woodring, W. P., Bramlette, M. N., and Kew, W. S. W., Geology and paleontology of Palos Verdes Hills, California: U. S. Geol. Survey Prof. Paper 207, 1946.

[4] Mulryan, Henry, Geology, mining and processing of diatomite at Lompoc, Santa Barbara County, California: California Div. Mines Rept. 32, pp. 133-166, 1936.

diatomite to the primary crushing plant underground. The overburden is stripped and much of the diatomite is now quarried with gasoline- and diesel-powered shovels. Quarrying by shovels begins at a convenient place on the outcrop, working along the strike of the beds to the end of the quarry, then new cuts are made at successive intervals down dip. Drilling and blasting is necessary only where nodules, layers, or beds of chert or chalcedony (called ''flint'') are encountered. The firm, compact, well-stratified form of the diatomite, its high water content, and its ease of cutting make mining operations relatively simple. Little timbering is required underground; there is no dust, no excess water, and no objectionable gas.

*Production of diatomite in California, 1889-1948.**

Year	Tons	Value	Year	Tons	Value
1889	39	$1,335	1914	12,840	$80,350
1890-92	0	0	1915	12,400	62,000
1893	50	2,000	1916	15,332	86,649
1894	51	2,040	1917	24,301	127,510
1895-96	0	0	1918	35,963	189,459
1897	5	200	1919	40,200	217,800
1898-1901	0	0	1920	60,764	1,056,260
1902	422	2,532	1921-22	90,739	1,016,675
1903	2,703	16,015	1923-25	193,064	5,729,736
1904	6,950	112,282	1926-28	275,403	1,995,923
1905	3,000	15,000	1929-31	300,017	4,848,661
1906	2,430	14,400	1932-34	203,228	3,104,154
1907	2,531	28,948	1935-37	290,908	4,243,572
1908	2,950	32,012	1938-40	266,358	3,941,941
1909	500	3,500	1941-43	425,745	6,692,051
1910	1,843	17,617	1944-46	460,654	9,324,111
1911	2,194	19,670	1947	[1]	[1]
1912	4,129	17,074	1948	[1]	[1]
1913	8,645	35,968			

* Since about three-quarters of California diatomite production is from a single operator, figures have been combined, in some instances, to conceal output of individual producers.

[1] Figures not shown since a 3-year combination is necessary to conceal output of individual producers. However, more diatomite was produced in 1947 than in any previous year.

Processing of the diatomite is done at the quarries. Natural brick is machine-sawed, dried in kilns under temperatures which reach 500° F., and then put through sizing machines. Two types of pressed brick are manufactured; one from a simple aggregate, and another from aggregate containing a binder. The bricks are then fired. Natural aggregate and calcined aggregate are made and sacked.

At the Dicalite operation, on land owned by W. C. H. Dibblee, 7 miles southeast of Lompoc, surface quarrying is done by carryall, and the product is piled for drying. It is then hauled by truck to the company's plant at Walteria, Los Angeles County, where it is processed along with diatomite from the same company's quarries nearby in the Palos Verdes Hills.

Markets. California, as the leading diatomite-producing state, is followed by Oregon, Nevada, and Washington; the last three produce relatively small amounts. Increasing amounts of diatomite are moving out of California to other states and also, since World War II, to foreign markets. The United States Bureau of Mines has not been at liberty to publish statistics on production since 1926, but gives total *sales* of diatomite as follows: [5]

Sales of diatomite, 1936-44.

	Short tons	Value
1936-38	279,645	$4,377,353
1939-41	360,502	5,746,216
1942-44	524,872	9,894,534

Quotations on diatomite products at the close of 1948 were: Crude, in bulk, nominal; 98 to 100 mesh, f.o.b., mill, Nevada, per ton $25; low-temperature insulation, per ton $25; high-temperature insulation, per ton $40; and fine abrasive, bags extra, per pound, 2 @ 3 cents.

DOLOMITE

By Clarence A. Logan and Lauren A. Wright

In the period 1941-43, the production of dolomite in California increased nearly 15-fold to an all-time high of more than 330,000 tons. This increase was caused by the installation of plants to produce magnesia and magnesium metal from sea water, a process in which dolomite is a necessary raw material. With the discontinuance of magnesium-metal production, the post-war dolomite output has declined to a yearly total of 200,000 to 250,000 tons, a volume that is still several times higher than the figure for any pre-war year. Most of the current output is consumed in the manufacture of magnesia and other magnesium compounds. This industry has successfully continued into the post-war period.

There are large reserves of dolomite in California, but the current operations are confined to relatively few localities. Most of the output is obtained from deposits south of Hollister in San Benito County, and at Natividad in Monterey County.

Mineralogy and Geologic Occurrence. The mineral dolomite is a double carbonate of calcium and magnesium ($CaMg(CO_3)_2$) which, in its pure state, consists of 45.7 percent $MgCO_3$ and 54.3 percent $CaCO_3$. Rock that approximates this composition is also called dolomite. Actually, the rocks limestone and dolomite are end members of a gradational series in which the minerals calcite and dolomite occur as physical mixtures in various proportions.

True dolomite rock contains 45 percent magnesium carbonate, high-magnesian limestone contains 25 to 45 percent, low-magnesian limestone contains 5 to 25 percent, and high-calcium limestone less than 5 percent.[1]

Large deposits of true dolomite are not common. In California, as elsewhere, most of the material marketed as dolomite is, by strict definition, high-magnesian limestone. The two terms will be considered as synonymous in this report.

It is generally believed that most of the occurrences of dolomite and magesian limestone were originally deposited as calcium carbonate and

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[5] Metcalf, R. W., and Holleman, A. B., Abrasive materials: Minerals Yearbook 1946, pp. 94-95, 1948.

[1] Colby, Shirley F., Occurrences and uses of dolomite in the United States: U. S. Bur. Mines Inf. Circ. 7192, pp. 1-2, 1941.

that the magnesium has replaced the calcium by infiltration and chemical reaction at some later time during the consolidation of the sediment.[2] In some deposits, limestone has been hydrothermally altered to dolomite long after sedimentation and lithification ceased. These deposits, however, are much less common and more irregular than those altered by saline surface waters. Dolomite is also a vein mineral commonly associated with metallic ores; but vein dolomite does not occur in deposits large enough to be of commercial value.

Most of the dolomite in California is of marine origin, and most is contained in beds of pre-Cambrian or Paleozoic age. Large deposits of dolomite occur in the Gabilan Range in San Benito and Monterey Counties; in the Mother Lode area on the west flank of the Sierra Nevada; in the Transverse Ranges north of Los Angeles; and in the desert areas of eastern and southern California.

San Benito and Monterey Counties. Most of the dolomite currently produced in California is obtained from deposits in the northern portion of the Gabilan Range in San Benito and Monterey Counties. In this region sedimentary rocks that have been correlated with the Sur series (pre-Franciscan) occur as roof pendants in the pre-Franciscan Santa Lucia granite.[3] The dolomite is obtained from high-magnesian portions of the Gabilan limestone, a part of the Sur series.

Dolomite deposits in an area 10 miles south of Hollister, San Benito County, were opened in 1915. In subsequent years, this area has become one of the two principal sources of dolomite in California. Five properties, the O'Hara, San Benito Vineyards Company, Leopold Palmtag, E. L. Martin Range, and Hamilton deposits, have been worked; others are undeveloped.

In recent years the Hamilton deposit, about three-quarters of a mile southwest of Vineyard has been the only one in operation. In 1947 this property was purchased by Westvaco Chemical Corporation which has since used the dolomite as a raw material in its magnesia plant at Newark. Most of the earlier production of dolomite in this area was used in the construction of refractory basic linings in open-hearth steel furnaces.

The most productive dolomite sources in California to date are the deposits at Natividad, 6½ miles northeast of Salinas, Monterey County. These deposits were opened in 1917, but were first worked on a large scale in 1942 with the beginning of an operation by Permanente Metals Corporation. The subsequent output of this operation totals several hundred thousand tons; it has been used in the production of magnesia and metallic magnesium.

In recent years the only other active property in the Natividad area has been one about half a mile north of the Permanente property. It has been worked on a modest scale for many years, first by Pacific Coast Steel Company, and, since 1940, by Bethlehem Steel Company. The output has been used in lining bottoms of open-hearth steel furnaces.[4]

Several other properties in the Natividad area have been worked in the past, but none of these has been active for 20 years or more.

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[2] Rockwood, N. C., Lime, in Industrial minerals and rocks, p. 471, Am. Inst. Min. Met. Eng., 1949.

[3] Allen, J. E., Geology of the San Juan Bautista quadrangle, California: California Div. Mines Bull. 133, pp. 17-22, 1946.

[4] Logan, C. A., Limestone in California: California Jour. Mines and Geology, vol. 43, p. 257, 1947.

Sierra Nevada. Although most of the limestone in the western Sierra Nevada has a low magnesium content (see section on lime and limestone) there are relatively large deposits of high-magnesian limestone in Tuolumne and Calaveras Counties.

To date, the principal production has been in the form of marble, which was quarried for a long time prior to 1940 by the Columbia Marble Company near Columbia. Recently, U. S. Lime Products Corporation has been producing dolomite and magnesian limestone from the same deposits. Sonora Marble Aggregates Company produces terrazzo and aggregates for built-up roofing from magnesian marble at Shaws Flat.[5]

Inyo County. The first dolomite produced commercially in California was obtained from a deposit on the southwest flank of the Inyo Range 3 miles northeast of Swansea, Inyo County. Here Paleozoic limestones have been hydrothermally dolomitized along a several-mile belt.[6] An analysis published in 1890 [7] indicates that the dolomite is nearly pure.

Dolomite was first produced in the Swansea area in 1888, and has been intermittently mined there since then. Until the early nineteen-hundreds most of the output was marketed as dimension stone in the San Francisco area. Since 1915 some of the dolomite has been sold to soda plants at Owens Lake, and much of it has been shipped to Los Angeles for use in terrazzo and stucco, and as steel furnace lining, flux, art stone, poultry grit, and roofing granules. Six quarries have been opened, but only one is currently active. Its product is crushed and screened at the operation site.

Southern California. The deserts of southern California contain numerous large deposits of dolomite in the pre-Cambrian and Paleozoic sediments which are extensively exposed throughout the region; but the demand for dolomite in the southern California area has not been large enough to support operations comparable in size with those of the Gabilan Range. They are also farther removed from consumption centers than the Gabilan deposits.

The Chubbuck Reserve deposits, in the Marble Mountains, 7½ miles northwest of Cadiz, were opened by the Kaiser Company, Incorporated, during World War II. Several carloads of dolomite averaging 19.8 percent contained MgO were shipped.

The Hinkley deposit, 4 miles south of Hinkley, was opened in 1944 and dolomite was shipped for a time to Kaiser Company's steel plant at Fontana. This dolomite contains about 21 percent MgO.

The Richter deposit, 10 miles north of Lucerne post office, was opened in 1943 and has been operated intermittently since by the Marter Mining Company. It contains some stringers of magnesite which raised the MgO content slightly above that of pure dolomite.

Utilization. More than three-quarters of the dolomite and dolomitic limestone quarried in the United States is used as crushed stone for concrete aggregate, road metal, riprap, railroad ballast, fertilizer, and soil conditioner. The remainder is used largely in refractories, basic magnesium carbonate or technical carbonate, in the manufacture of paper, blast furnace flux, and in agricultural applications. There are many other minor uses.[8]

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[5] Logan, C. A., op. cit., pp. 175-357.
[6] Smith, Ward C., personal communication.
[7] DeGroot, H., Inyo County: California Min. Bur. Rept. 10, p. 218, 1890.
[8] Colby, S. F., op. cit.

In California the dolomite and high-magnesium limestone used for constructional purposes is not reported as such but classified as stone, miscellaneous. Little dolomite, however, has been used for this purpose in the state because of the abundance of other suitable rock types.

The chief applications of dolomite in California depend upon its chemical properties. At present the largest tonnage is used in plants making magnesium compounds from sea-water and sea-water bittern. The dolomite for this purpose is calcined, finely comminuted, and mixed with the sea-water or bittern, with which it reacts to precipitate magnesium hydroxide. Dolomite has replaced calcined oyster shells for this purpose (see section on magnesium compounds).

Several thousand tons of dolomite are used annually, both crude and calcined, as a refractory for repairing the hearths of open-hearth steel furnaces. During World War II, the largest tonnage of dolomite produced in California came from the Natividad quarry, Monterey County. The dolomite was used for producing metallic magnesium at the Permanente Metals Corporation Manteca plant, and at their Moss Landing plant for making magnesia. At Manteca the Pidgeon ferrosilicon process was used to produce magnesium (see section on magnesium compounds). Dolomite from Natividad is no longer used for making metallic magnesium but this quarry continues to supply the Moss Landing plant. Dolomite from this quarry is also used for roofing granules, for refractory material, for agricultural applications, and to make lime for chemical and building uses.

Small tonnages of dolomite in California are used for making lime, stucco dash rock, terrazzo, kalsomine, poultry grit, mineral wool, and carbon dioxide. For most of these purposes, dolomite is in competition with limestone. Dolomite is available in California for building stone but it is not being produced as such at present.

Markets. As dolomite is a low-priced, large-volume product, it must be mined as close as possible to centers of consumption. So far as known, there has been no sale of local dolomite outside the state, with the possible exception of a little marble. The price is about the same as for limestone but most of the dolomite mined recently has been captive tonnage, for which any prices quoted would not be those of an open competitive market.

Mining Methods and Treatment. In mining dolomite, the same technique is employed as that used for other low-priced stone products. This includes open quarry or bench workings to permit use of power shovels and large bank blasts. Primary crushing and the separation of waste is done at the quarry to minimize the cost of handling. Calcining kilns similar to those used for making lime are employed. These are vertical or rotary kilns. In California, crude oil and natural gas are used for fuel. Small-scale operation of a dolomite quarry in this state is likely to be successful only where it has some distinct advantages such as nearness to a market and conditions that permit very cheap quarrying.

FELDSPAR

By Lauren A. Wright

The feldspar produced in California from 1910 to 1946 totals more than 160,000 tons, but has never exceeded 15,000 tons for any given year. Since 1945 the industry has been nearly dormant. Approximately 10,000 tons of feldspar from out-of-state sources are reported to be marketed in California each year. Nevertheless numerous potentially commercial feldspar deposits exist in California; these include undeveloped properties as well as those that have been worked in the past. In California pegmatite dikes have been the only sources of commercial feldspar.

Mineralogy and Geology. The minerals of the feldspar group are essentially silicates of aluminum with potassium, sodium, or calcium. They are the most common constituents of igneous rocks. The principal feldspar species are orthoclase and microcline (both $KAlSi_3O_8$), albite ($NaAlSi_3O_8$), and anorthite ($CaAl_2Si_2O_8$). These ideal compositions, however, are rare in nature; orthoclase and microcline generally contain appreciable amounts of soda; albite and anorthite are end members of a continuous series known as plagioclase. Plagioclase also generally contains a small amount of potash. Microcline and orthoclase commonly contain albite in regular intergrowths; such intergrowths, known as perthite, constitute most of the commercial potash feldspar.

The average igneous rock is composed of nearly 60 percent feldspar,[1] but until recently the only source of commercial feldspar has been very coarse-grained pegmatite masses. Increasing amounts of feldspar are now being obtained by froth flotation of finer-grained pegmatites and other igneous rocks, but as yet this process has not been used commercially in California. In the future, a similar treatment may well prove practical in the beneficiation of certain feldspathic beach sands in the state.

The principal minerals of pegmatites are the same as those of ordinary igneous rocks. Pegmatites range in composition from acidic to basic, but the granitic type, in which feldspar, quartz, and mica predominate, is the most common and has been the source of most commercial feldspar. Pegmatites occur in dikelike bodies within or near larger bodies of igneous rocks. They are best known for the extremely large grain size which certain of the mineral components commonly develop and for the rare-element bearing minerals that occur in some, though by no means all, pegmatite dikes. In many dikes the mineral-grain sizes increase from the walls inward. The largest, most easily mined feldspar masses are near the centers of many of the dikes. Individual feldspar grains or crystals several feet in length are not uncommon in such concentrations. Quartz, the most abundant impurity, ordinarily occurs as irregular masses, as veinlets, or as regular intergrowths with potash feldspar.

Though the famous gem-bearing pegmatites of San Diego County have been studied in some detail,[2] relatively few geological data are available on the pegmatites in California from which feldspar has been obtained. Published economic reports[3] indicate that most, if not all, contain potash-rich feldspar. They have been described in general as relatively simple, elongate dikes in which feldspar and quartz are the only abundant minerals; most occur within bodies of granitic rocks.

Localities. Pegmatites associated with the late Jurassic (?) igneous rocks of the Peninsular Ranges province of Riverside and San Diego Counties have contributed most of the feldspar produced in California.

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[1] Clarke, F. W., Analyses of rocks and minerals: U. S. Geol. Survey Bull. 419, p. 9, 1910.

[2] See section on gems in this bulletin.

[3] Sampson, Reid J., and Tucker, W. B., Feldspar, silica, andalusite and cyanite deposits of California: California Div. Mines Rept. 27, pp. 407-458, 1931.

Individual feldspar properties have also been described in various county reports issued by the California Div. Mines.

The Pacific mine, about 5 miles north of Campo in San Diego County, was operated continuously for approximately 20 years. During this period, which ended in 1942, the mine yielded more than half the state's total feldspar production. The Elder feldspar mine, also near Campo, operated during a 10-year period ending in 1929.

A mine about 3 miles north of Murietta, Riverside County, operated by the American Encaustic Tiling Company, was active during the period 1919-30. This property was principally a silica mine, but a substantial tonnage of feldspar was also obtained. Production has also been reported from approximately 30 other operations in the Peninsular Ranges province, but all were shorter-lived and smaller producers than the three mentioned above. Several, however, had single-year outputs that exceeded 1,000 tons; these include the Tully and La Borde deposits near Lakeview, the Blom deposit near Perris, and the Machado deposit 3 miles north of Winchester.

Much of the early production of feldspar in California centered around a group of pegmatite dikes in late Jurassic (?) granitic rocks in the vicinity of Three Rivers and Lemon Cove, Tulare County. The combined production for the district, however, did not exceed 8,000 tons, and all activity was confined to the period 1911-20. Another early producer was the J. C. Jens mine about 5 miles east of Chualar, Monterey County. From 1911 to its last activity in 1920, this property yielded about 5500 tons of feldspar.

Since the late thirties, three deposits, other than the Pacific deposit near Campo, have been active. In 1940 Gladding, McBean and Company began to operate a deposit about 30 miles northwest of Barstow, San Bernardino County. Though production recently has been relatively small, the property, in its first few years of operation, was worked on a scale comparable with that of the Campo deposit, and it is still intermittently operated. From 1937-44 a small annual production was obtained from the Childers mine about 4 miles northwest of Auberry, Fresno County. In 1946 the Anderson mine near Oakhurst, Fresno County, was also operated on a small scale.

Other scattered feldspar operations not mentioned above, but which have contributed appreciable tonnages, include the Nine-mile Canyon property five miles west of Linnie, Inyo County; the Sweetzer and the Burns and Grant properties near Rosamond, Kern County; and the Sloan deposit 3½ miles north of Hinkley, San Bernardino County.

Enormous deposits of anorthosite, consisting largely of unusually pure concentrations of the plagioclase andesine,[4] are exposed in the western San Gabriel Mountains. Attempts to quarry feldspar in this area have failed, because of the difficulty of finding a market.

North Carolina produces nearly half the national feldspar output, which during recent years has ranged from a third to a half million long tons. Other important feldspar-producing states are South Dakota, Colorado, Virginia, Wyoming, Maine, and Connecticut.

Preparation and Utilization. Preparation of crude feldspar simply involves grinding to specified sizes and, when necessary, the removal of iron-rich material by magnetic separation. In many areas that are near

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[4] Miller, W. J., Geology of the western San Gabriel Mountains of California: Univ. California Los Angeles, Pub. Math. and Phys. Sci., vol. 1, 1935.
Oakeshott, Gordon B., Geology and mineral deposits of the western San Gabriel Mountains, Los Angeles County: California Div. Mines Rept. 33, pp. 215-259, 1937.

centers of feldspar consumption, coarse-grained feldspathic pegmatites do not exist, or have been worked out. In such areas it has proved practical to recover feldspar by froth flotation of finer-grained rocks.

More than 98 percent of ground feldspar consumed nationally is marketed to the ceramic industry. In recent years approximately two-thirds of the output has been used in glass manufacture, and one-quarter in pottery production. All of the glass sand currently produced in California is feldspathic and requires little or no additional feldspar. Much of the feldspar formerly produced in the state was used as a raw material in the manufacture of floor-and-wall tile, but talc and tremolite have largely replaced feldspar in this use. Almost all of the feldspar now shipped into California is consumed in ceramic uses other than the manufacture of wall tile.

Mining Methods and Prices. In California, as elsewhere, most of the feldspar has been removed by quarrying, though a few mines have employed underground methods. During the last years of active feldspar mining in the state, crude feldspar at the mine was valued by the producers at about $5.00 per ton.

FLUORSPAR

By Charles W. Chesterman

Fluorspar is an important nonmetallic industrial mineral used principally as a flux in the open-hearth process of steel manufacture. The development of an iron and steel industry in California has increased the consumption of metallurgical- and acid-grade fluorspar; but the production of fluorspar in California has been small and intermittent and has not been able to keep pace with the demands made by the steel industry. The total fluorspar production in California to date has been but a few hundred tons and none was mined in 1947. The bulk of acid and metallurgical grades of fluorspar consumed in California comes from Nevada.

Geologic Occurrence and Localities. Fluorspar or fluorite (CaF_2), is the only commercially important fluorine-bearing mineral. When pure, it contains 48.9 percent fluorine and 51.1 percent calcium. It occurs in a great variety of geological settings—as fissure fillings, as replacement deposits in sedimentary rocks, as fillings of solution cavities near faults, and as residual deposits.

In California, fluorspar deposits have been reported in Inyo, Kern, Los Angeles, Lake, Mono, Riverside, San Bernardino, San Diego, Santa Clara, Tulare, and Yolo Counties. Among the deposits that have attracted attention as potential commercial sources of fluorspar are those in the Deep Springs Valley, the Darwin district, and in the Panamint Range, Inyo County; in the White Mountains, Mono County; in the Little Maria and Palen Mountains, Riverside County; in the Cave Canyon mining district, and in the Providence, Riverside, Shadow, and Sidewinder Mountains, San Bernardino County.

In Deep Springs Valley, Inyo County, deep-purple fluorspar occurs in veinlets in metamorphosed limestone. The veinlets range from a fraction of an inch to several inches in thickness; the larger ones contain quartz, orthoclase, and muscovite.[1]

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[1] Knopf, Adolph, Mineral resources of the Inyo and White Mountains: U. S. Geol. Survey Bull. 540, pp. 81-120, 1912.

In the Darwin district, Inyo County, coarsely crystalline fluorite occurs as a gangue mineral in the silver-lead deposits.[2]

At a deposit on the north slope of Warm Spring Canyon, Panamint Range, Inyo County, fluorspar occurs in veins from 1 foot to 10 feet wide cutting Archean granite gneisses. The CaF_2 content ranges from 29 to 65 percent.[3]

In Mono County, fluorspar occurs with andalusite, muscovite, damourite, lazulite, corundum, pyrophyllite, and rutile in the Champion Sillimanite Incorporated mine, on the western slope of the White Mountains.[4] At a locality near the north end of the Palen Mountains, eastern Riverside County,[5] green, white and purple fluorspar occurs as disseminated grains and bunches closely associated with malachite and azurite in fault zones cutting quartz monzonite. At a deposit on the east slope of the Little Maria Mountains about 14 miles south of Rice, Riverside County, fluorspar occurs in parallel veins from 18 inches to 3 feet in width in quartzite and mica schist. An analysis representative of 130 tons, which in 1944 was shipped from this deposit to the National Supply Company, Torrance, California, showed 87 percent CaF_2; 4 percent SiO_2; 0.47 percent CaO; 2.25 percent Al_2O_3; and 0.15 percent Fe_2O_3.

The largest number of known fluorspar deposits in California are in San Bernardino County. Numerous veins of fluorspar occur in the Cave Canyon mining district, near Afton. Here the fluorspar is associated with fine-grained andesitic rocks which occur as intrusive bodies or as flows. The volcanic rocks are fractured, and form breccias which in places contain much crystalline fluorspar. The fluorspar-bearing zones of brecciated andesite are irregular and range from 1 foot to 50 feet in thickness. They are traceable for nearly 2000 feet on the surface. Some of the fluorspar occurs in veins that range from a few inches to 4 feet in thickness. The richer parts of the fluorspar-bearing zones locally contain 10 to 40 percent fluorite, but such areas are small. Both silica and calcite are present, but metallic sulfides are lacking. Analysis of the ore showed a range of 35 to 86 percent CaF_2; 8 to 44 percent SiO_2; and 2 to 29 percent $CaCO_3$.[6]

Fluorspar occurs with sericite in replacement veins of variable thickness along discontinuous shear zones in dolomite on the north side of Clark Mountain near Mountain Pass, San Bernardino County.

Another fluorspar deposit is located a few miles east of Nipton, near the California-Nevada boundary line. The fluorspar occurs in gneiss in veins from 12 inches to 3 feet wide. The ore is low grade, and would require concentration to bring it up to a marketable product,[7] with the exception of one narrow vein which has yielded material containing 85 percent fluorite.

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[2] Knopf, Adolph, Darwin silver-lead mining district, California: U. S. Geol. Survey Bull. 580, p. 7, 1913.

[3] Personal communication from Richard M. Stewart, California Div. Mines, September 16, 1949.

[4] Jeffery, J. A., and Woodhouse, C. D., A note on the deposits of andalusite in Mono County, California; its occurrence and technical importance: California Div. Mines Rept. 27, p. 461, 1931.

[5] Tucker, W. B., and Sampson, R. J., Mineral resources of Riverside County: California Div. Mines Rept. 35, p. 164, 1945.

[6] Burchard, E. F., Fluorspar deposits in western United States: Am. Inst. Min. Met. Engr. Trans., vol. 109, pp. 373-374, 1933.

[7] Burchard, E. F., op. cit., p. 395, 1933.

Other deposits of fluorspar in San Bernardino County include occurrences in the southern part of the Riverside Mountains, 26 miles south of Cima; in an area half a mile south of Baxter; with lead and copper minerals at copper and silver mines in the New York Mountains, a few miles west of Barnwell; as irregular lenses in quartz veins cutting granite in southwestern outliers of the Ord Mountains; and as irregular bunches and stringers along fissures in limestone on the northeast slope of Shadow Mountain, Silver Mountain mining district.[8]

Utilization. The steel industry consumes more than 52 percent of the fluorspar used in the United States; about 28 percent is used in the manufacture of hydrofluoric acid. Most of the remainder is consumed in the manufacture of glass, enamel, cement, and welding rods.

In the steel industry the chief use of fluorspar is for metallurgical purposes, especially as a flux in the making of steel by the open-hearth process. The fluorspar used in the steel industry must contain at least 85 percent CaF_2 and not more than 6 percent SiO_2 or 0.2 to 0.3 percent sulfur. Fluorspar gives fluidity to the slag and is an important aid in removing sulfur and phosphorus. Small amounts of fluorspar are used in refining gold, lead, copper, and antimony.

In the manufacture of hydrofluoric acid (HF) an exceptionally pure grade of fluorspar is used. It must contain at least 97.5 percent CaF_2; not more than 2.0 percent $CaCO_3$, 1.0 percent Al_2O_3, and 1.0 percent Fe_2O_3; and no manganese or chromium. In the glass industry fluorspar is used to make opalescent, opal, opaque, and colored glass. These glasses are used for lamp globes and shades, light bulbs, containers for toilet and medicinal preparations, tableware, and novelties. High-grade fluorspar, containing at least 97 percent CaF_2, is an important constituent in dense, opaque, white, and colored enamels used for coating all sorts of kitchen and sanitary wares, plumbing fixtures, stoves, refrigerators and table tops. It is also used as facings for brick and tile, art pottery, structural materials, earthen ware, and similar ceramic products where an opaque, easily fusible enamel is needed.

Large amounts of impure acid grade fluorspar are used in the manufacture of artificial cryolite which is used with natural cryolite in the production of metallic aluminum by electrolysis. A small amount of clear, transparent, nearly colorless fluorspar is used in the manufacture of certain types of lenses.[9]

Markets. No fluorspar was produced or marketed in California during 1947. In 1917-18, 79 tons valued at $991 were shipped from Riverside County. In 1933-34, 227 tons, valued at $3631, were shipped from San Bernardino County; and in 1944-45, 130 tons worth $4290 were shipped from Riverside County. United States output of fluorspar in 1947 was 329,484 tons valued at $10,954,875, and the imports for the same year were 78,725 tons. Of the 1947 total, 9,185 tons were consumed in California.

Metallurgical-grade fluorspar containing 70 percent calcium fluoride was quoted at $37.00 per short ton f.o.b. at the mines in Illinois and

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[8] Tucker, W. B., and Sampson, R. J., Mineral resources of San Bernardino County: California Div. Mines Rept. 39, pp. 513-514, 1943.

[9] Averill, C. V., and others, California mineral production for 1946: California Div. Mines Bull. 139, pp. 72-73, 1948.

Tarr, W. A., Introductory economic geology, pp. 570-574, New York, McGraw-Hill Book Company, Inc., 1930.

Kentucky. Acid-grade calcium fluoride containing not less than 97 percent calcium flouride sold at $43.50 per short ton at the mines in Illinois.[10]

GEM STONES

By Lauren A. Wright

Gem mining in California has centered about the famous gem-bearing pegmatite area of San Diego and Riverside Counties. The combined reported value of the gem tourmaline, spodumene, beryl, topaz, and garnet thus far produced is more than $2,000,000. Though this value is relatively small compared with that of other mineral commodities of the state, the area has been one of the nation's few notable gem-producing districts.

At other localities in the state deposits of benitoite, chrysoprase, idocrase, jade, and turquoise have also been developed as serious mining ventures. Gem mining was most active in California during the period 1890-1912. From 1880-1924 California produced 23 percent of the gem material mined in the United States.[1] In addition to the recorded output, an unknown, but undoubtedly large, volume of material has been removed from gem mines and prospects by high-graders. The very large amount of gem material and ornamental stone collected by thousands of mineral enthusiasts at many undeveloped localities is also unrecorded.

Gems from the pegmatites of San Diego and Riverside Counties.[2]

Tourmaline (a complex silicate of boron and aluminum) has been produced in greater quantity than any other gem stone mined in California. The black variety, schorl, is a mineral common in many pegmatites throughout the world, but rarely does tourmaline occur in the transparent red, pink, green, or blue gem-quality varieties. In numerous pegmatites in San Diego and Riverside Counties, however, such gem tourmalines are present. They occur as transparent, elongate prisms, characteristically pencil-like in shape and size. Some crystals have diameters of over 4 inches and lengths of greater than a foot. Many of the prisms and prism clusters are as valued for mineral specimens as for gem material, and are comparable in size and beauty to the world's finest tourmaline.

Unusually transparent varieties of the mineral spodumene (a silicate of lithium and aluminum) have also been extensively mined as one the valued gem materials of the pegmatites of San Diego and Riverside Counties. A delicate pinkish to lilac variety has been given the name "kunzite."[3] This variety was first discovered in the Pala district, but since has been mined from localities in Madagascar and Brazil. Other gem varieties of spodumene in the southern California pegmatites range from blue-green to almost colorless. The gem spodumene crystals are lath-like. They are characteristically somewhat rounded, and attain a length of nearly one foot.

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[10] Eng. and Min. Jour., Metal and mineral markets, vol. 21, no. 1, New York, McGraw-Hill Publishing Company, Inc., Jan. 1950.

[1] Ball, S. H., Precious stones, in Industrial minerals and rocks, p. 306: Am. Inst. Min. Met. Eng., 1937.

[2] Jahns, R. H., The gem deposits of southern California: Eng. and Sci. Monthly, vol. 11, no. 2, pp. 6-9, Feb. 1948.

Jahns, R. H., and Wright, L. A., The pegmatites of the gem and lithium districts, San Diego County, California: California Div. Mines, in press.

[3] Baskerville, Charles, Kunzite, a new gem: Science, new ser., vol. 18, pp. 303-304, 1903.

The mining of pegmatites, chiefly in the search for tourmaline and spodumene, has led to the recovery of gem varieties of quartz, pink beryl (morganite), topaz, and essonite garnet. These also are noted for their transparency and color.

Most of the principal gem mines are contained in a 25-mile belt entirely within San Diego County and extending southeasterly from Pala through Rincon to Mesa Grande. Within this belt the pegmatites are clustered in districts, one near each of these three settlements. Gem minerals have also been obtained from pegmatites near Coahuila in Riverside County, and from the Bonsall, Aguanga Mountain, Ramona, Julian, and Jacumba districts in San Diego County.

The Himalaya mine in the Mesa Grande district has been the principal gem-tourmaline source in North America. The Pala district, represented by such mines as the Tourmaline King, Tourmaline Queen, Stewart,[4] Pala Chief, and Vanderburg-Katerina, is equally famous as a source of tourmaline and spodumene.

All of the gem mines of the region [5] are in the Peninsular Ranges province which is underlain principally by igneous rocks of the late Jurassic (?) southern California batholith. Most of the pegmatite is contained in relatively basic units of the batholith.

Nearly all of the pegmatite is in elongate dikes which range in thickness from a fraction of an inch to 100 feet or more. Most of the pegmatite is graphic granite (a regular intergrowth of quartz in microcline feldspar), but many dikes are composed of well-defined units of contrasting composition and texture. Some of these dikes contain graphic granite in their upper portions, and an evenly layered, fine-grained pegmatite in their lower portions. The fine-grained pegmatite, known locally as ''line rock,'' consists mainly of albite, but garnet and black tourmaline are also common constituents.

In some of the dikes a quartz-rich ''pocket zone'' is at or near the graphic granite-line rock contact. In this zone feldspars, muscovite, tourmaline of various colors, beryl, and other rarer minerals accompany the quartz. A few of the gem crystals are imbedded in solid pegmatite, but most are partly to wholly surrounded by a pinkish-brown clay.

In the pegmatites that contain gem tourmaline, topaz, garnet, or beryl, there is little relation between the thickness of the dike and the gem content. Quartz-spodumene concentrations, however, commonly occupy the centers of bulges in the pegmatites. The spodumene crystals, which are long and lath-like, are ordinarily decomposed to a clay-like substance. Clear, gem-quality spodumene occupies the center of some of the crystals and appears to represent material that has escaped alteration.

Owing largely to the narrowness of the productive ''streak'' in the gem-bearing pegmatites, underground mining methods have been

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[4] The Stewart mine, most actively worked during the period 1900-20, was an important domestic source of lepidolite and was operated principally for this mineral as a source of lithium.

[5] Among the earlier descriptions of these deposits and their constituent minerals are the following:

Kunz, G. F., Gems, jewelers' materials and ornamental stones of California: California Min. Bur. Bull. 37, pp. 46-101, 1905.

Schaller, W. T., Spodumene from San Diego County, California: Univ. California, Dept. Geol. Sci. Bull., vol. 3, pp. 265-275, 1903.

Schaller, W. T., The genesis of lithium pegmatites: Amer. Jour. Sci., 5th ser., vol. 10, pp. 273-276, 1925.

Sterrett, D. B., Tourmaline from San Diego County, California: Amer. Jour. Sci., 4th ser., vol. 17, pp. 459-465, 1904.

employed the most; though open cuts were used wherever the overburden was not too great. Inclines of gentle to moderate slope and drifts followed those pegmatite units where the gems were thought most likely to occur. Hand methods were employed in most of the mines and but little timbering was required.

The first recorded discovery of gem tourmaline in California was made near Coahuila in 1872.[6] In subsequent years this and other occurrences were developed on a small scale, but not until 1893 was the next major discovery, that of tourmaline and lepidolite in the Pala district, made known. Five years later, in 1898, the Himalaya deposit near Mesa Grande was discovered. In 1902 the Pala district became the discovery site of the first gem-quality spodumene, but the mineral was not identified until a year later. The period 1902-03 also witnessed the discovery of gem tourmaline at Aguanga Mountain, kunzite near Coahuila, garnet, beryl, tourmaline, and topaz near Ramona, and garnet near Jacumba.

The pegmatite gems of southern California were mined most intensively from 1902 to 1912. Overproduction caused a rapid market collapse shortly before World War I and the mines have since seen little activity. During World War II a small quantity of Pala tourmaline, which had been previously mined, was sold as piezoelectric material. Also during World War II small amounts of piezoelectric quartz were obtained from the Senpe pegmatite in the Pala district. Interest is currently being shown in a revival of several operations, but production on a scale comparable to that of the early nineteen-hundreds is not anticipated.

During the period of active mining, cut tourmaline gems commanded from $2 to $10 per carat; current prices are slightly higher. Facet-cut kunzite is now marketed at $2 to more than $25 per carat, depending upon the nature and depth of its color. Facet-cut, colorless to blue topaz is finding a ready market at prices ranging from $5 to $15 per carat. Quartz, beryl, and garnet are valued at considerably less than tourmaline, kunzite, and topaz.[7]

Benitoite. Benitoite ($BaTiSi_3O_9$), a mineral found only in California, has become well known for its beauty and for its unique crystal habit. It was discovered in 1907 in San Benito County at a locality on the west side of the Diablo Range 25 airline miles north of Coalinga. Grains of benitoite were obtained from drill holes in the Lost Hills area, Kern County,[8] but no other occurrences have been found.

Though some specimens are colorless, most of the benitoite is pale to dark sapphire blue. The mineral has a hardness greater than 6 and an imperfect cleavage, and is the only known representative of the trigonal class, hexagonal system.[9]

The benitoite, accompanied by neptunite [$(Na,K)_2(Fe,Mn)(Si,Ti)_5O_{12}$] and joaquinite (a titano-silicate of calcium and iron), occurs in veins of massive natrolite ($Na_2Al_2Si_3O_{10} \cdot 2H_2O$) which transect tough blue rock composed largely of soda amphibole. The property was worked by the Dallas Mining Company until 1912. Since then it has lain idle, but resumption of production is anticipated by the present lessee. Most of the

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[6] Kunz, G. F., op. cit., pp. 21-27.

[7] Jahns, R. H., The gem deposits of southern California: Eng. and Sci. Monthly, vol. 11, no. 2, pp. 8, 9, Feb. 1948.

[8] Reed, Ralph D., and Bailey, J. P., Subsurface correlations by means of heavy minerals: Am. Assoc. Petroleum Geologists Bull., vol. 11, p. 363, 1927.

[9] Louderback, G. D., Benitoite, its paragenesis and mode of occurrence: Univ. California Dept. Geol. Sci. Bull., vol. 5, pp. 331-380, 1909.

output has been sold as specimen material but many of the larger, flawless crystals of good color have been cut as gem stones. Such cut stones now bring prices that range from $20 to $40 per carat.

Chrysoprase. Chrysoprase, an apple-green variety of chalcedony, has been noted at several localities in the western Sierran foothills. In Tulare County it has been actively mined. The first discovery was made in 1878 at Vince Hill 12 miles northeast of Visalia. By 1898 four other chrysoprase occurrences in Tulare County had been discovered. These properties were worked until shortly after 1902 when activities were curtailed. The shut-down was due largely to the waning popularity of chrysoprase as a gem stone. As described by Tucker,[10] chrysoprase in this area occurs as narrow veins in a jasperoid rock. Cabochon-cut chrysoprase currently demands from $2 per carat up, the price depending largely on color and degree of translucency.

Idocrase (Vesuvianite). Californite, a massive, compact variety of the mineral idocrase (a basic calcium-aluminum silicate), has been recognized at localities in Butte, Fresno, and Siskiyou Counties. The name was originally applied by Kunz [11] in 1905 to material obtained from a deposit in Siskiyou County about 10 miles northwest of Happy Camp. The deposit was discovered about 1900 and for a few succeeding years was actively mined. During this period other deposits in the same area were located. Californite has also been mined from a deposit near Pulga in Butte County. This property is reported to have been active in 1910.[12] At the properties in both Siskiyou and Butte Counties the californite occurs as pods or lenses in serpentine.

Californite was first mistaken for jadeite, a mineral which it closely resembles. The best grades of californite have a translucent green color, and polish to a brilliant luster. A splintery fracture is also characteristic of the mineral.

Californite did not have a wide market, and the deposits have not been actively mined for many years.

Turquoise. The mining of turquoise was vigorously pursued in San Bernardino County for a several-year period that began about 1898. The turquoise was obtained from a group of mines in the Solo mining district of San Bernardino County. The mines had previously been worked by Indians.[12a]

According to Kunz,[13] the turquoise occurred in narrow seams, nodules, and pockets in quartzite. Much of the turquoise is reported to have been a good quality gem material. The operators, however, found the deposits disappointingly shallow. The mines were abandoned early in the century, and have not been worked since.

Quartz. Much of the early production of the quartz crystals from placer deposits at Chili Bar, Calaveras County, is reported to have been sold as gem and ornamental material; but the properties underwent their greatest development during World Wars I and II, when the quartz was marketed for optical and piezoelectric uses. These operations are dis-

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[10] Tucker, W. B., Tulare County: California Min. Bur. Rept. 15, p. 310, 1919.

[11] Kunz, G. F., op. cit., pp. 93-95.

[12] Sterrett, D. B., Gems and precious stones: Mineral Resources U. S., 1910, pt. 1, p. 358, 1911.

[12a] Heizer, R. F., and Treganza, A. E., Mines and quarries of the Indians of California: California Div. Mines Rept. 40, pp. 335-336, 1944.

[13] Kunz, G. F., op. cit., p. 108.

cussed more fully in the section on quartz crystal in this bulletin. As mentioned above, gem-quality quartz crystal has also been obtained from pegmatites in southern California.

Gold-bearing quartz obtained from numerous lode deposits in the state has also been widely used as a gem material. Amethyst quartz has been mined at a deposit near Howard Springs, Lake County, and has been obtained in the Bodie district, Mono County. Rose quartz has been found in several deposits of the Sierran foothill counties and in the pegmatites of southern California.

Diamond. A few diamonds have been obtained from gold-placer operations in the Sierran foothill belt and in Siskiyou and Trinity Counties. The most noted diamond-bearing area is in the Cherokee Flat district of Butte County, where more than 300 diamonds have been recovered. No primary diamond deposits have yet been discovered in the state, but the placer occurrences probably originated in the ultrabasic igneous rocks from which the Sierran foothill belt serpentine masses were derived. A serpentinized pipe-like body of rock, that was believed to resemble the diamond-bearing kimberlite of South Africa, was noted near Oroville, Butte County in 1906.[14] Recovery of diamonds at this locality was subsequently attempted, but was unsuccessful.

Jade. Several tons of medium to dark green nephrite jade, a compact variety of tremolite or actinolite, were mined during 1949-50 from a lens included in serpentine near Porterville, Tulare County. This is the largest body of nephrite found to date in California. Much of the material produced has been of excellent color, translucency, and cutting quality, and has been marketed principally to amateur lapidarists.

Miscellaneous Gem Stones. Space does not permit, nor are there sufficient data to allow the listing of all other localities in California from which gem or ornamental stones have been obtained, but some of the more notable materials, which have not been actively mined, or which have been obtained as by-products of other mining operations can be mentioned.[15]

Silica minerals other than the quartz and chrysoprase described above have been collected at widely scattered localities throughout the state. Chalcedony, a translucent to opaque cryptocrystalline form of silica has been deposited in cavities or fissures in many areas. Chalcedony is commonly more resistant to weathering than the enclosing rock, and it tends to concentrate in stream beds and shore deposits. Jasper, a variegated and opaque variety of chalcedony is one of the state's most common gem materials. Myrickite, a cinnabar-bearing chalcedony, has been obtained from a locality 45 miles east-northeast of Johannesburg, San Bernardino County, and from several mercury deposits in California. Opal, a hydrous and amorphous silica mineral, is also common in California; but gem-quality opal has been noted at relatively few localities.

Smithsonite ($ZnCO_3$) is best known in California as a zinc ore in the Cerro Gordo district, Inyo County, and at several localities in San

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[14] Sterrett, D. B., Precious stones: Mineral Resources U. S., 1906, pt. 2, pp. 1217-1219, 1907.

[15] Sperisen, F. J., Gem minerals of California: California Div. Mines Rept. 34, pp. 34-78, 1938.

Bernardino County. Though a rather soft mineral, much of it has been cut as a gem stone.

GRAPHITE

By Gordon B. Oakeshott

Graphite is widely distributed in pre-Cretaceous metamorphic rocks throughout California, but graphite produced in the state has had difficulty in meeting competition provided by the higher quality imported material. For a period of 50 years prior to 1935 graphite was produced spasmodically, chiefly from Sonoma and Los Angeles Counties, but no production has been recorded since that date.

Mineralogy and Geologic Occurrence. The mineral graphite, also called plumbago, is a crystalline form of pure carbon. It belongs to the hexagonal system and is characterized by softness, perfect basal cleavage, and greasy feel. A commercial distinction made between "amorphous" and "crystalline" graphite is based solely on relative grain size; the "amorphous" variety is composed of finer crystalline grains than the "crystalline" variety. Some commercial graphite is manufactured by heating coke in an electric furnace.

Much graphite has been formed by the metamorphism of carbonaceous sediments, including coal, with resultant crystallization of the carbon. Such graphite occurs in schists and gneisses of sedimentary origin. However, some is found associated with intrusive igneous rocks, and with pegmatites; these occurrences strongly suggest an igneous origin. The mineral is also a constituent of meteorites.

Graphite in California is found in schists and gneisses most, if not all, of which are of sedimentary origin. While the graphite schists are certainly pre-Cretaceous in age, many of the age assignments given to specific occurrences are uncertain and have ranged from pre-Cambrian to Upper Jurassic. In Los Angeles County, where graphite has been mined at several places, it occurs in crystalline limestone, quartzite, and feldspar-sillimanite-tremolite schists, all of which are metamorphosed sedimentary rocks which have been intruded by plutonic rocks such as diorite and granite.

Localities. A third of the counties of California have occurrences of graphite schists which have been prospected, but production has come almost entirely from Mendocino, Sonoma, and Los Angeles Counties.

Early operations included two in northern California, one 15 miles east of Pt. Arena, Mendocino County, and another 4 miles south of Petaluma, Sonoma County;[1] the latter was opened in 1894. In each deposit the graphite occurs in metasedimentary schist of the Franciscan group. The graphite was used in San Francisco in the manufacture of paint, as a lubricant, and in foundry facings.

In Los Angeles County a number of graphite occurrences have been worked. A deposit in the Sierra Pelona near the head of San Francisquito Creek was worked at intervals for more than 25 years prior to 1931.[2] Here a graphite schist was formed through metamorphism of carbonaceous sediments. A maximum daily output of 10 tons of graphite was

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[1] Aubury, Lewis E., The structural and industrial materials of California: California Min. Bur. Bull. 38, pp. 279-281, 1906.

[2] Simpson, Edward C., Geology and mineral deposits of the Elizabeth Lake quadrangle, California: California Div. Mines Rept. 30, p. 409, 1934.

mined and milled. Three samples, analyzed by the United States Geological Survey, ranged from 7.29 to 17.48 percent graphite. The plant operated continuously from 1918-20 and supplied some of the local needs for foundry facings, paint, and lubricants.

A deposit on the north slope of the Verdugo Hills, 2½ miles northwest of Montrose, was known as early as 1889; some ore was mined in 1920. This deposit and others in Los Angeles County were discussed by Beverly.[3] Deposits in upper Kagel Canyon (on the divide between Kagel and Limerock Canyons) and several in Pacoima Canyon and vicinity were described by Oakeshott [4] who included a petrographic description of the metasedimentary graphitic schists and a detailed geologic map of the area. The graphite in Kagel Canyon resulted from metamorphism of the Placerita sedimentary series, remnants of which remain as crystalline limestone, quartzite, and various more-or-less graphitic schists. At least two periods of metamorphism and intrusion are represented by the presence of hornblende diorite (Rubio gneiss) and Upper Jurassic (?) granite and granodiorite. A 50-ton concentration mill was constructed at the Kagel deposit and produced small-flake graphite between 1918 and 1928. The ore carries 7 to 15 percent graphite in flakes less than 0.25 millimeter in diameter.

Utilization. The properties of graphite which make it most useful are its resistance to chemical action and the action of molten metals, its infusibility, opacity, softness, and perfect cleavage. Its most common uses are in electrical appliances, ''lead'' pencils, lubricants, stove polish, paint, foundry facings, scale-preventative for boilers, mold wash for steel mills, polishes, and in powder glazing. Some of these uses can be supplied by artificial graphite made from coke as well as by the natural product.

California deposits generally carry graphite in flakes too small to command the best prices paid for flake graphite which can be used in crucibles and refractories. However, California graphite is suitable for paints and foundry facings.

Production and Markets. The inability of domestic graphite to compete with imported or artificial graphite is illustrated by the small number of United States producers, as well as by California's lack of production since 1935. Several times the domestic production was imported from foreign countries, chief among them being Mexico (Sonora), Ceylon, Madagascar, and Canada. The U.S.S.R. is a large producer, but does not release statistics.

Production of natural graphite in the United States

	Short tons
1942	7,120
1943	9,939
1944	5,408
1945	4,888
1946	5,575

Strategic minerals to be stock piled in the United States now include crucible-grade flake graphite, the high-carbon flake, and amorphous graphite.

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[3] Beverly, Burt, Jr., Graphite deposits in Los Angeles County, California: Econ. Geology, vol. 29, pp. 346-355, 1934.

[4] Oakeshott, Gordon B., Geology and mineral deposits of the western San Gabriel Mountains, Los Angeles County: California Div. Mines Rept. 33, pp. 245-248, 1937.

Prices paid for graphite vary greatly with the form and quality, as shown by the following summary of recent prices f.o.b New York.

Imported amorphous, powd., bgs., lb.	\$.04-.08
Crystalline 88-90 percent, powd., bgs., lb.	.16-.19
Flake No. 1, 90-95 percent, bgs.	.21-.22
Ceylon lump, lb.	.10-.12
Carbon lump, lb.	.09-.10
Dust	.04-.05
Madagascar No. 1, flake	.09-.16
Madagascar No. 2, flake	.07-up
Fine ground 55-70 percent	.03-up
Crude amorphous, ton	\$14-\$30

LIME AND LIMESTONE

By Oliver E. Bowen, Jr.

Lime (CaO) and limestone ($CaCO_3$ + impurities) are closely allied materials. Although most lime is produced by calcining limestone, a considerable tonnage is also marketed as a by-product in the manufacture of other commodities. By-product limes do not fall within the scope of this summary.

Mining and processing of lime materials is a multimillion dollar business in California. By far the largest consumer of natural lime materials in the state is the portland cement industry which had a gross 1948 output valued at \$57,742,226. Details of this branch of the lime industry can be found under the heading *Cement* in this bulletin. Manufacture of hydrated lime and quicklime for use in the construction industry has decreased with expanded use of portland cement; but the use of lime as an industrial chemical and as a soil conditioner in agriculture has expanded tremendously so that lime production in California over the years has substantially increased.[1]

Geologic Occurrence of Lime Materials in California. In California, lime is manufactured principally from massive crystalline limestone. One cement plant uses loose accumulations of sea-shells from San Francisco Bay. With few exceptions, California limestones occur in ancient metamorphosed sedimentary rocks; most of these are Paleozoic. One or two Tertiary deposits of shell limestone are economically important.

Most limestone originates as chemically or organically precipitated ooze, as accumulations of the calcareous parts of marine or lacustrine organisms, or as a combination of both types of material. Such deposits form on both sea and lake floors, but marine deposits are by far the most extensive. Evaporation of carbonate-laden spring water occasionally forms deposits sufficiently extensive to exploit; one of these was utilized at Cowell in Contra Costa County for portland cement. Consolidation and lithification of soft, water-laid calcareous ooze generally involves widespread re-solution, cementation, and crystallization to form an interlocking mass of calcite grains. The resulting finely crystalline limestone is normally a dense, compact rock considerably softer than granite, and much more susceptible to chemical decomposition by acid ground water. Metamorphism by heat and pressure may further recrystallize limestone into a coarser-grained rock that is more resistant to chemical and physical breakdown.

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[1] Harness, C. L., and Gradijan, F. D., Lime: Minerals Yearbook 1946, pp. 708-723, 1948.

Pure limestone consists entirely of calcite ($CaCO_3$). The calcium of the calcite molecule may be partly replaced by magnesium, iron, or manganese, resulting in a slightly impure limestone. Many impure limestones, however, contain a variety of carbonate and silicate minerals. There is a complete gradation from pure limestone to pure dolomite ($CaCO_3 \cdot MgCO_3$). The term dolomite is used both as a mineral name and as a rock name; limestone is predominantly calcite, whereas dolomite rock consists mainly of the mineral dolomite. Other carbonates such as siderite ($FeCO_3$), magnesite ($MgCO_3$), and rhodochrosite ($MnCO_3$), are sometimes present.

Silica-bearing minerals such as chert (cryptocrystalline quartz), detrital quartz, and feldspars may be present as original constituents of the limestone beds. Silicates such as serpentine ($H_4Mg_3Si_2O_9$), wollastonite ($CaSiO_3$), and tremolite ($CaMg_3Si_4O_{12}$) may develop in limestones during metamorphism. Garnet, vesuvianite, and a host of other complex silicates may develop in limestone near igneous contacts. Development of silicate minerals commonly results in a poorer grade of limestone for most purposes.

Physical and chemical properties of limestone vary widely and utilization may depend upon one or the other of these sets of characters. For example, the value of commercial marble (a dense limestone or dolomite that will take a high-polish),[2] is dependent upon its physical characters; its chemical composition is of much less importance. Conversely, limestone for portland cement and for many industrial uses must meet rigid chemical requirements. Many crystalline limestones contain magnesium in sufficient quantity to make them unsuitable for use in portland cement, but these are being increasingly used for many other purposes. Dolomitic limestones (limestones containing from 10 to 45 percent $MgCO_3$, and also known as magnesium or magnesian limestones), once considered undesirable for calcining to lime, have been found satisfactory for that purpose. Limestone for flux in steel furnaces may be dolomitic: pure dolomite ($MgCO_3 \cdot CaCO_3$) is sometimes used for similar purposes.

Limestone and dolomite commonly are interbedded in the same formation, sometimes in massive layers that can be mined separately, but often in narrow interbeddings which cannot be selectively mined. Mill separation of such mixed materials is not now economically feasible, but it may become so in the future. Mining of many bodies of crystalline limestone is further complicated by intrusive igneous rocks which disrupt the continuity of the deposit and add undesirable minerals to the limestone.

Calcareous shells of salt- and brackish-water mollusks are used in portland cement at one plant on the southern arm of San Francisco Bay. Shells have been accumulating for many thousands of years on the bay floor and at several points form deposits extensive enough for major exploitation. They occur in loose masses from which the lime carbonate can be produced by ordinary dredging and washing methods.

Limestone deposits occur in all but a few of California's 58 counties. They are widely distributed in a western Sierran belt which extends from Plumas County to Kern County. Most Sierra Nevada deposits are asso-

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[2] The term marble is also loosely used in the limestone trade as a synonym for crystalline limestone.

ciated with the Paleozoic Calaveras formation. In the Coast Ranges, limestone deposits have been extensively quarried in Solano, Santa Clara, Santa Cruz, and Contra Costa Counties. Coast Ranges limestones are found either in the upper Jurassic Franciscan formation or in the pre-Franciscan Sur series. Limestones are widely distributed through the Mojave Desert but current production comes chiefly from the Victorville-Oro Grande district. Upper Paleozoic formations such as the Oro Grande series and the Furnace limestone contain very extensive reserves. Lower Paleozoic formations of the Klamath Mountains, Siskiyou County; the Permian McCloud limestone of Shasta County; the Upper Paleozoic of the northern San Bernardino Range; the pre-Upper Jurassic metasediments of the San Jacinto Mountains of Riverside County; and the Paleozoic formations of the desert mountains of Inyo and Mono Counties, all contain notable limestone reserves.[3] At present, 25 producers are active in the following counties: El Dorado, Fresno, Inyo, San Bernardino, San Diego, San Luis Obispo, San Mateo, Santa Clara, Santa Cruz, Siskiyou, Tuolumne, and Ventura.

Mining and Manufacturing Methods. In California limestone is mined principally by surface methods. Establishment of a new quarry usually consists of laying out a level quarry floor and then driving a face above this level. In a few deposits it is necessary to work down from the quarry level; these tend to be more expensive to exploit than above-level deposits. At Crestmore, Riverside County, limestone is mined by block-caving and shrinkage stoping, rock being removed via several haulage levels and a five-compartment vertical shaft. One mine in El Dorado County and one in Tuolumne County also use underground methods. Ordinarily, rock is blasted by explosives from the working face to the quarry floor below. Explosive charges are laid partly in holes drilled from above, parallel to the face, and partly in ''coyote'' holes driven more or less perpendicularly to the face.

Transportation from quarry to mill is usually either by truck, rail, or both. Heavy trucking equipment is finding wider use compared to the less flexible rail equipment. Rock at the Permanente operation near Los Altos in Santa Clara County is moved from quarry to plant by 48-inch belt conveyors.

Treatment of limestone at the mill depends upon its ultimate utilization. For a great many purposes only grinding is required. For poultry grit or terrazzo, a moderately coarse grind is necessary. As a filler and for most purposes as an industrial chemical, a finely divided product is necessary. For roofing granules and for some types of filler, particle shape is important and both raw materials and milling equipment are selected to produce a maximum quantity of particles of preferred shape.

Calcining (burning) limestone at temperatures between 750° C. and 950° C. converts it to quicklime (CaO) and carbon dioxide (CO_2) gas. The dissociation temperature of pure limestone is 750° C. but CO_2 ordinarily is not completely driven off at that temperature. Presence of water, magnesia, and other impurities changes the temperature of dissociation. Finely crystalline limestone is preferred to coarsely crystalline material for burning to lime because of its greater strength. Limestone is placed in most lime kilns in lump form and must retain considerable strength

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[3] Logan, C. A., Limestone in California: California Jour. Mines and Geology, vol. 43, pp. 175-350, 1947.

during the calcining process. Coarsely crystalline limestones often disintegrate to small particles which inhibit the efficiency of some types of kilns.

Lime kilns are either rotary (horizontal) or shaft (vertical) type.[4] Quicklime comes from the kiln in lumps. If it is to be marketed in dehydrated form it is ordinarily left in lumps to reduce chances of hydration. Most lime is sold in hydrated form ($CaO{\cdot}H_2O$) ; the hydrate is produced by slowly adding water to quicklime. Slaking of quicklime is accomplished either by exposure to moist air or by grinding and thorough mixing with the proper proportion of water to give a hydrated but not damp product. Sieving is the final step to produce a uniform powder. Air slaking produces the smallest increase in volume over the unslaked product, but is a much slower process than liquid hydration. Hydrated lime is marketed both in bags and in bulk lots. Quicklime must be packaged in airtight containers—barrels or drums.

History of Production. Production of lime and limestone in California dates back to the Spanish period. Ruins of lime kilns which burned limestone for local use are widely scattered throughout the state; some of these were left by the Spaniards, but most were early American. Calcined lime for mortar was in great demand during the gold-rush period and the pioneering years that followed. Demand often exceeded the local supply, and large quantities were shipped into California from foreign countries through the port of San Francisco.

Use of limestone in the construction industries markedly decreased when, with the advent of portland cement, lime mortars were supplanted by cement mortars, and masonry by concrete. The decreased use of lime in construction was largely offset by its increased use as an industrial chemical.

Figures on amount and value of California lime and limestone show great annual fluctuations not generally shown by most other mineral commodities. In the case of tonnage produced, this trend results mainly from the delicate balance between the cost of production and the market value of low-cost mineral materials, among which limestone is one of the lowest. Another factor is the small number of large-scale producers who have operated over a long period of time as compared with the large numbers of small-scale temporary operators. A third factor is that many consumers purchase and stock pile several years' supply, which is mined and reported within a 1-year period.

Fluctuations in value of lime products are largely the result of non-uniformity in quality and condition of the product reported. One producer, for example, will report his annual production in terms of tons of processed limestone, whereas another will report in terms of unprocessed rock as valued at the quarry. Another factor, which affects the average computed price from which the total value is taken, is the variability in price obtained for the many grades of limestone marketed. This price fluctuation results in part from the variability of California limestone deposits and, in part from changing demand for the different grades.

Centers of Production. Lime and limestone operations are widely distributed in California. Limestone is known to accur in 47 of the 58 counties, but so far has been utilized in only 37. Kilns which once burned

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[4] Taggard, A. F., Handbook of mineral dressing, pp. 3-46 to 3-60. New York, John Wiley & Sons, 1945.

lime for local use could utilize small deposits which now cannot be operated at a profit. Many limestone and marl quarries that produced for local agricultural purposes have likewise operated intermittently. As a result, many properties which formerly produced are now idle. At present, 27 properties in 13 counties produce lime products. These do not include properties which produce limestone for portland cement exclusively, or properties which produce road metal or aggregate. Counties now producing limestone or lime products are El Dorado, Fresno, Inyo, Orange, San Bernardino, San Diego, San Luis Obispo, San Mateo, Santa Clara, Santa Cruz, Siskiyou, Tuolumne, and Ventura. Of this group, San Bernardino, El Dorado, Santa Cruz, and Santa Clara are the principal sources.

Enormous tonnages of undeveloped high-calcium limestone in California remain to be exploited when the demand becomes sufficiently great. The largest undeveloped or partly developed reserves are found in Shasta, San Bernardino, and Riverside Counties, and the several counties comprising the foothill belt of the Sierra Nevada. Most of these limestone bodies are either too distant from rail facilities or, as in the case of Shasta County, are too far from marketing centers to be commercially exploited under present conditions.

Utilization and Markets. Limestone is a basic raw material for a great variety of products. Most of these fall into one of five main groups, namely, agricultural products, construction materials, metallurgical materials, industrial chemicals, and fillers. Only the most common uses can be listed here.

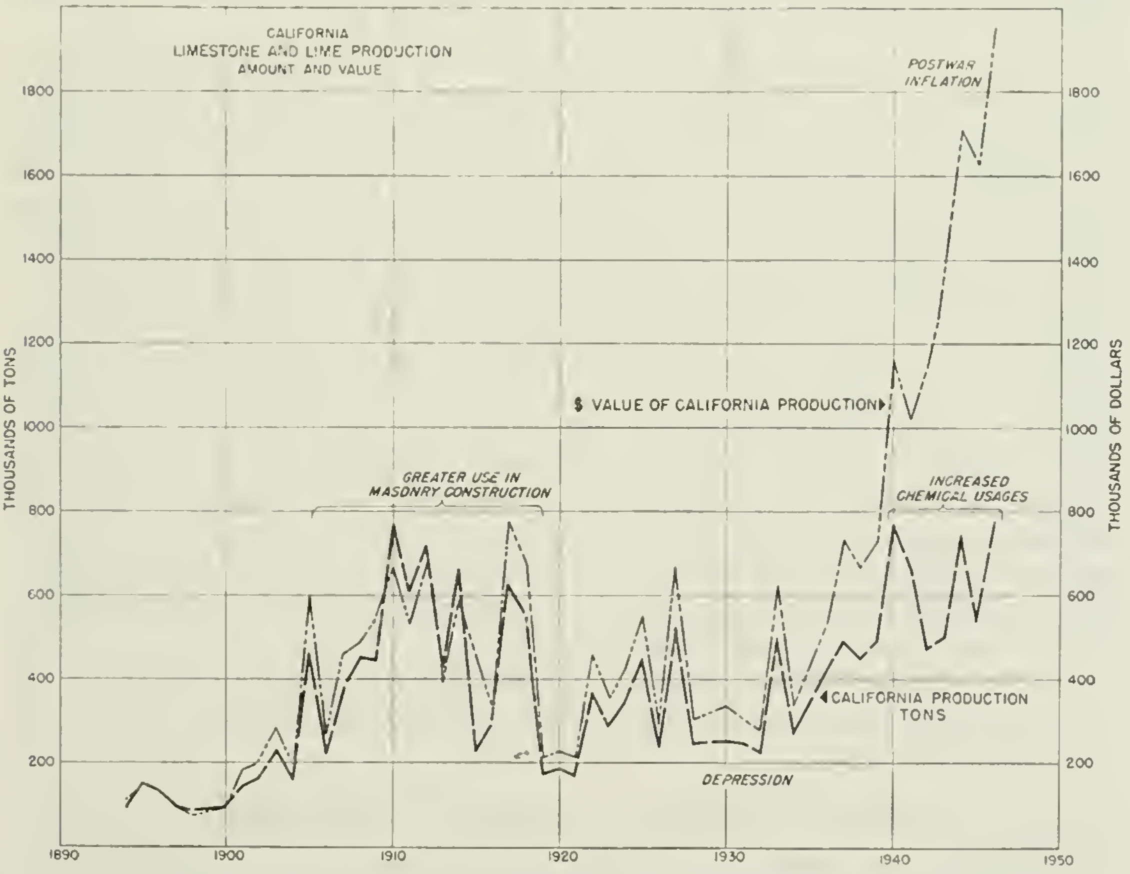

FIGURE 1. Chart showing amount and value of lime and limestone produced in California, 1894-1946, exclusive of limestone used in portland cement.

Agricultural limes are used principally as soil additives. As such they are applied in the form of ground limestone, hydrated lime, or filler in mixed commercial fertilizers. Minor uses of lime and limestone in agriculture are: in pulverized form in stock feed; in crushed, sized form for poultry grit; and in finely divided form in liquid sprays and dry-powder insecticides. Use of lime as a soil additive will steadily increase as California soils become depleted in lime with long usage. Most virgin California soils are not deficient in lime.

Lime products are important constituents in various construction materials. Portland-cement mills consume the largest tonnage used by construction industries. Quicklime and hydrated lime are also used in quantity in mortar, plaster, stucco, and masonry cement. Lime is used to some extent as an additive in concrete where it gives workability and water-proofing properties. Sand-lime brick and silica brick are common refractory materials made in part from hydrated lime. Production of limestone and marble for use as building blocks and facings has dwindled to a very low figure because of competition with low-cost synthetic materials such as terrazzo, tile, and art concrete. California is well supplied with ornamental marbles of great beauty and could supply them in quantity if the demand should arise.

With the advent of a major steel industry in California, production of limestone and dolomite for basic flux has become rather large. Some limestone for flux is produced by steel manufacturers for their own use, but a great deal is bought on the open market. Minor metallurgical uses for lime are: in the cyanide process for gold and silver recovery; in flotation of various metallic ores; and in settling slimes produced during milling of ores.

Lime, as an industrial chemical, is extensively used in the manufacture of soda ash (Na_2CO_3), calcium carbide (CaC_2), and calcium cyanamide ($CaCN_2$). As a water-purifying agent, hydrated lime causes precipitation of calcium bicarbonate from hard water and coagulates solid material in sewage to facilitate settling and filtration. Several chemical plants produce magnesia (MgO) by action of calcined dolomite on bitterns. Many paper plants use lime in preparation of cooking liquor. Tanneries use quick-slaking lime for removing hair from hides, and rendering companies use lime in manufacture of gelatin and glue. Plants manufacturing sugar from beets calcine lime, and both the lime and the carbon dioxide gas are utilized. Some other industries use the carbon dioxide evolved during calcining of limestone, but enormous volumes of the gas are wasted. Lime is used as a neutralizer of acids in petroleum refining, varnish manufacturing, and numerous other processes. High-magnesium and high-calcium limestones are both utilized in the manufacture of glass. Limestones for glass must contain very low percentages or iron, sulfur, and phosphorus.

Ground limestone, precipitated lime hydrate, and slaked lime are all used as fillers in various products, particularly in paper, paint, oilcloth, and linoleum.[5]

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[5] Usage of lime and limestone is a very large subject ordinarily discussed under a variety of headings. The following references cover many of the different uses for lime and limestone:

Bowles, Oliver, Chalk and whiting: U. S. Bur. Mines Inf. Circ. 7197, 21 pp., Feb. 1942.

Banks, D. M., Lime: U. S. Bur. Mines Inf. Circ. 6884R, 48 pp., Oct. 1941.

Bowles, Oliver, and Jensen, Nan C., Industrial uses of limestone and dolomite: U. S. Bur. Mines Inf. Circ. 7402, 19 pp., May 1947.

MAGNESITE, MAGNESIUM, AND MAGNESIUM COMPOUNDS

By James W. Vernon

Four plants in California are now producing magnesium compounds. Two are on San Francisco Bay—one at Newark, the other at South San Francisco; a third is at Moss Landing, Monterey County; and a fourth is at Chula Vista, San Diego County. In the period 1937-43 the annual output of magnesium compounds in California increased from less than 4,000 to more than 110,000 tons. California thus became one of the three leading states in the production of these materials. During World War II large quantities of magnesium compounds were used in California in the production of magnesium metal; but, elemental magnesium production was discontinued in 1946. In 1948 about 38,500 tons of magnesium compounds were produced in the state.

The principal raw materials used in the production of metallic magnesium and magnesium compounds are raw sea water, sea water bittern, dolomite, and magnesite. Magnesia (MgO) is the principal magnesium compound produced. In the past California has been one of the principal domestic sources of magnesite; but the state's known, easily recoverable magnesite reserves are near depletion. Magnesia and other magnesium compounds are now, however, prepared principally from sea water, sea-water bittern, and dolomite. Reserves of easily obtainable dolomite in California are large.

Magnesium Compounds and Metallic Magnesium Production. The magnesium compounds produced at the four California plants are dead-burned and caustic-calcined magnesia, basic magnesium carbonate, magnesium carbonate, magnesium hydroxide, and magnesium chloride.

Most of the magnesia produced in California is made by calcining magnesium hydroxide which is derived from sea water and dolomite. Additional quantities are obtained by calcining the minerals magnesite ($MgCO_3$) and brucite ($Mg(OH)_2$), both of which are now brought into California from sources in Nevada. In industry the term ''magnesite'' is commonly applied to magnesia manufactured from any of these raw materials, but in the present discussion it will apply only to the mineral.

Common dead-burned magnesia has been calcined at about 1,560°C., and contains 65 to 88 percent magnesium oxide. Artificial periclase is a form of dead-burned magnesia which usually contains over 90 percent magnesium oxide, and has been calcined at about 1,760°C.[1] Caustic-calcined magnesia has been calcined at a temperature not exceeding 1200°C., and is a chemically reactive substance. Oil or natural-gas fired horizontal rotary kilns are used in the calcining. All of the magnesium compounds produced in California, except magnesium chloride and the magnesia obtained from magnesite, are made in conjunction with the operations producing magnesia from sea water or sea-water bittern. The magnesium chloride is produced at the Chula Vista plant where it is isolated from sea-water bittern by evaporation and fractional crystallization, a process that does not involve the production of magnesia.

Limestone as a building material: U. S. Bur. Mines Inf. Circ. 7416, 16 pp., Oct. 1947.

Logan, C. A., Limestone in California: California Jour. Mines and Geology, vol. 43, pp. 180-200, 1947.

O'Meara, R. G., Gow, A. M., and Coghill, W. H., Compendium on limes in hydrometallurgy and flotation: U. S. Bur. Mines Inf. Circ. 6423, 54 pp., Apr. 1931.

[1] Harness, Charles C., and Jensen, Nan C., Marketing magnesite and allied products: U. S. Bur. Mines Inf. Circ. 7269, p. 6, Dec. 1943.

The pioneer work in the commercial production of magnesium compounds from sea water was done by the Magnesium Products Company of South San Francisco. The process developed by this company, and followed in principal by other producers, including the plant of Permanente Metals Company at Moss Landing, involves essentially the replacement of magnesium salts in sea water by calcium salts and the concurrent precipitation of magnesium hydroxide.[2] The first step is the removal of organic and solid matter by killing the organic material with chlorine gas and settling it with the solids in flocs or agglomerates of magnesium hydroxide. The water is then filtered and magnesium hydroxide is precipitated by the addition of calcined dolomite which also supplies magnesium. The magnesium hydroxide is then removed and purified.

Bittern is used as raw material at the Newark plant in a process similar in many respects to that used in the sea-water process. Bittern is obtained from nearby salt works of the Leslie Salt Company. It is essentially a saturated solution of sodium chloride, but also contains magnesium sulfate and magnesium chloride.

The first major step in this operation is the precipitation of calcium sulfate (synthetic gypsum) by the addition of calcium chloride solution (the calcium chloride is the filtrate from the later step in which magnesium hydroxide is precipitated). Finely divided calcined dolomite is added to the filtrate from the first step to precipitate magnesium hydroxide. After filtering and washing, the composition is adjusted, if desired, principally by the addition of finely divided silica. It is then calcined to produce periclase and a variety of caustic-calcined products. The dolomite used at Newark is calcined and ground at the plant.

Metallic Magnesium. In the United States two types of processes have been used to produce metallic magnesium—electrolysis of magnesium chloride, and thermal reduction of magnesium oxide. The two principal thermal processes are the carbothermic (Hansgirg), and the ferrosilicon (Pidgeon). Previous to World War II all the magnesium produced in the United States was obtained by the electrolytic process at plants of the Dow Chemical Company at Midland, Michigan, and at Freeport, Texas. The thermal reduction processes were used in 14 other plants which were built during World War II, and which ceased operations at the end of the war. At present all of the domestic primary magnesium output is produced by the Dow Chemical Company at Freeport, Texas. This plant uses the electrolytic process.

Two plants made metallic magnesium in California during World War II. The carbothermic reduction (Hansgirg) process was employed in a plant at Permanente, Santa Clara County, and the Pidgeon ferrosilicon process was employed in a plant at Manteca, San Joaquin County.

In the carbothermic process, caustic-calcined magnesia and carbon are heated in excess of 2000°C. in a closed electric-arc furnace. The magnesia is reduced and the magnesium liberated as a vapor which is shock-cooled by natural gas. The magnesium dust thus produced at Permanente was used to make "goop" for large incendiary bombs or was briquetted and distilled to produce magnesium ingots.

In the Pidgeon ferrosilicon process calcined dolomite and ferrosilicon are mixed, briquetted, and heated to about 1150°C. in a highly

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[2] Ryder, David W., Magnesium salts from the sea, Marine Magnesium Products Corp., South San Francisco, California, 1947.

evacuated retort. The reduced magnesium condenses in the cooler end of the retort. The ferrosilicon used at Manteca was manufactured at Permanente (see section on ferro-alloys).

History of Production of Magnesium Compounds and Metallic Magnesium in California. Magnesia was first produced in California from magnesite. Production from this source began in the late eighteen-eighties and continued until 1945. The state's first production of magnesium compounds from material other than magnesite was obtained in 1916 by a salt company in the San Francisco Bay area. In this operation magnesium chloride was won from bittern obtained during the solar evaporation of sea water for sodium chloride.

In 1923, predecessors of the present Westvaco Chemical Division of the Food Machinery and Chemical Corporation built one plant at Chula Vista near San Diego Bay, and another at San Mateo near San Francisco Bay. These operations produced magnesium chloride and bromine from sea-water bittern obtained from salt plants. The San Mateo plant was operated until 1929 when operations were shifted to Newark, Alameda County. Here a constant supply of bittern was obtainable from nearby salt works. Bromine and magnesium chloride were the first commodities produced at the Newark plant; but since 1938 the plant has also produced artificial gypsum and various grades of magnesia.[3] This plant was the principal United States producer of periclase prior to World War II. For several years previous to 1946 the Westvaco organization also mined and calcined magnesite from the Red Mountain district.

In 1927 small amounts of magnesium sulphate and magnesium carbonate were produced by the American Magnesium Company from a dry lake bed 30 miles east of Searles Lake in Inyo County. Poor transportation facilities and excessive amounts of sand in the beds forced cessation of this operation.

In 1928 the world's first commercial production of magnesium hydroxide from raw sea water was obtained at the Marine Magnesium Products Corporation of South San Francisco, a plant which continues to produce high-grade magnesium compounds for industrial and pharmaceutical applications. The Plant Rubber and Asbestos Company of Redwood City, San Mateo County, produced basic magnesium carbonate from salt works bittern during the period 1933-47. In 1947 this plant was converted for production of asbestos-cement.

World War II brought impetus to the magnesium products industry in California. Production was increased at the established plants and new operations were begun. The Permanente Metals Corporation built a plant at Moss Landing to make periclase and various other grades of magnesia from sea water and calcined dolomite. Periclase produced at this plant was, and still is, used in the manufacture of refractory brick. Another product, caustic-calcined magnesia, was used as raw material for the metallic magnesium produced at Permanente during World War II. During World War II the Defense Plant Corporation established at Newark a plant which produced from bittern a magnesia catalyst used in the manufacture of synthetic rubber.

The plants at Manteca and Permanente, constructed in 1941 and 1942, produced magnesium metal urgently needed in aircraft and pyro-

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[3] Trauffer, W. E., Lime, gypsum and magnesite produced from sea water and shells at new plant in California: Pit and Quarry, vol. 30, no. 11, pp. 43-51, May 1938.

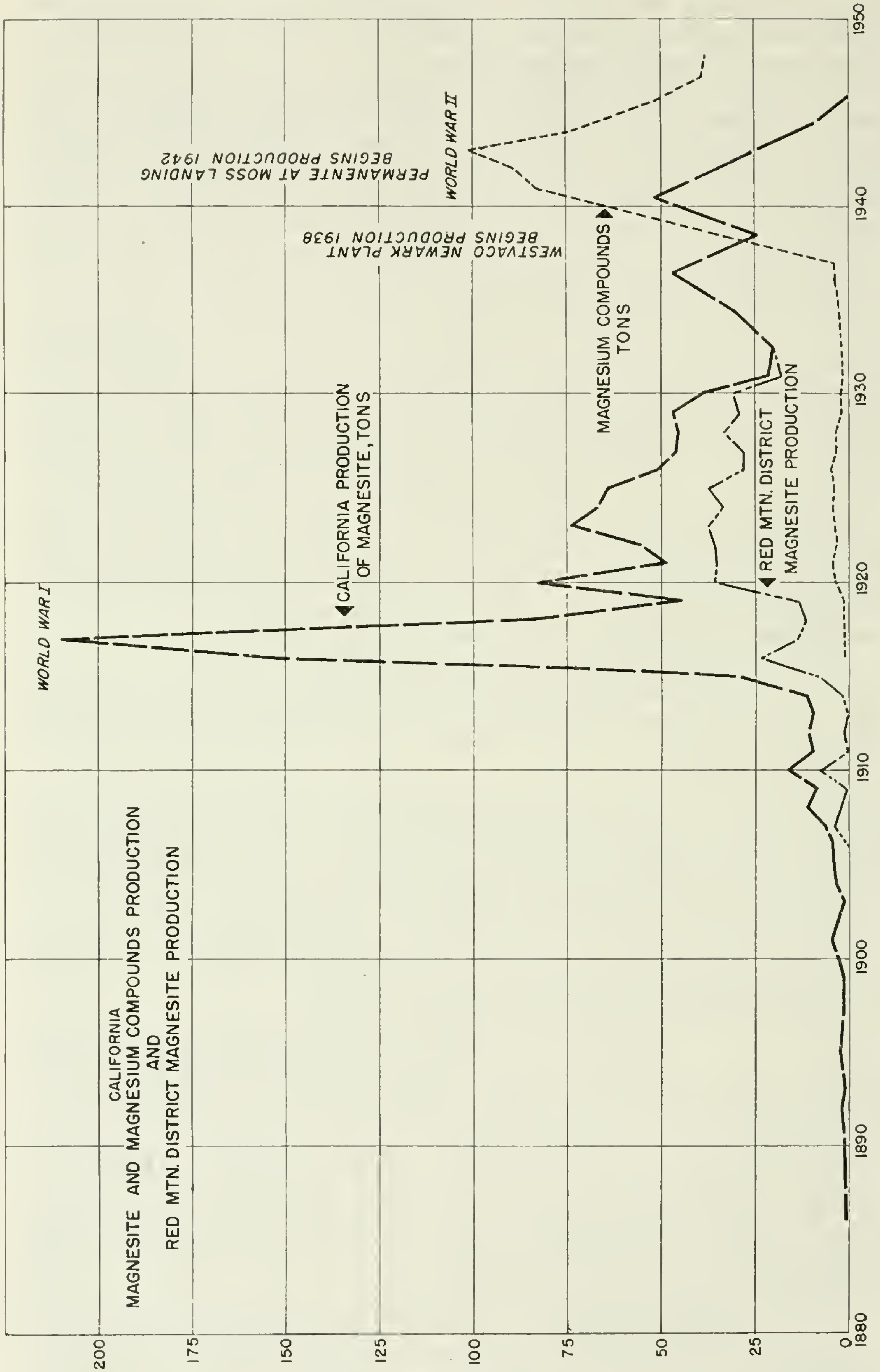

FIGURE 1. Chart showing production of magnesite in California (1886-1946) and in Red Mountain district (1906-32); and production of magnesium compounds in California (1916-48). Points on Red Mountain curve represent 2-year averages.

technics. Both were operated by the Permanente Metals Corporation. The plant at Permanente operated from late in 1941 until 1945. In 1946, fifty-six tons of magnesium were produced at Permanente in an experimental run which attempted to reduce operating costs by conversion from batch to continuous distillation of the crude dust.[4] The plant at Manteca operated from August 1942 to May 1944.

In 1944 reduced military requirements forced the curtailment of magnesium-metal production, and none has been produced in California since 1946. Some of the facilities used for processing magnesium metal at Permanente are currently being used in making aluminum foil.

Raw Materials. The mineral magnesite ($MgCO_3$) has three major geologic occurrences: (1) as a dolomite replacement related to intrusive igneous rocks; (2) as veins in serpentine; and (3) as a chemical precipitate in playa lakes. The world's largest magnesite deposits (in Austria and Manchuria) as well as the largest in the United States (at Chewelah, Washington, and Gabbs, Nevada) are of the dolomite replacement type. The magnesite of these deposits is crystalline as contrasted with the cryptocrystalline variety that is characteristic of the magnesite that occurs in serpentine.[5]

Most magnesite deposits in California are in ultrabasic rocks which are exposed in the Coast Ranges and the western Sierra Nevada. The deposits are of hydrothermal origin and occur as fissure fillings and replacements. At least two deposits in the state are of sedimentary origin.

The largest known magnesite deposits in California are in the Red Mountain magnesite district of Santa Clara and Stanislaus Counties.[6] The deposits in this district are confined to an area of about 2 square miles. Most of the output has been obtained from two mines, the Western and the Bald Eagle. These deposits have formed in a sill-like ultrabasic intrusive body, and occur as fissure fillings in breccia zones and shears, and as nodular replacements. The magnesite is characteristically white, porcelain-like, and cryptocrystalline. Associated minerals are dolomite, manganese oxide, chalcedony, opal, deweylite, sepiolite, and calcite. These minerals are believed by Bodenlos to have been deposited in the epithermal zone by ascending hot aqueous solutions charged with carbon dioxide, the magnesium and silica in the solutions having been derived by solution of the intrusive rock at depth. The largest ore bodies have been found at irregularities in the shear zones.

Deposits in Tulare and Napa Counties have also yielded significant amounts of magnesite, and are also associated with serpentine. Deposits near Porterville in Tulare County comprise a series of narrow, discontinuous, intersecting veins of magnesite in serpentine. Basalt and diabase have intruded the serpentine in the magnesite-bearing areas.[7] The largest deposits in Napa County were the Snowflake, Blanco, and White Rock. Other Coast Range counties from which magnesite has been produced are Sonoma, Alameda, San Benito, Mendocino, and Kings. The deposits on the eastern side of the Sacramento Valley, other than those in Tulare County, are in Placer and Fresno Counties.

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[4] Nighman, C. E., and Trought, Mary E., Magnesium: Minerals Yearbook 1946, pp. 724-735, 1948.

[5] Birch, R. E., and Wicken, O. M., Magnesite and related minerals, in Industrial minerals and rocks, 2d ed., pp. 522-523, Am. Inst. Min. Met. Eng., 1949.

[6] Bodenlos, A. J., Geology of the Red Mountain magnesite district, Santa Clara-Stanislaus Counties, California: California Jour. Mines and Geol., vol. 46, pp. 223-278, 1950.

[7] Tucker, W. B., Mines and mineral resources of Tulare County: California Div. Mines Rept. 25, p. 922, 1915-16.

Sedimentary magnesite deposits have been mined at Bissell, Kern County, and at Afton, San Bernardino County. At these localities magnesite is interstratified with clays, clay shales, and limestone, and probably formed by direct deposition of magnesium carbonate from concentrated saline waters.[8]

The first recorded magnesite production in California was from the Cedar Mountain District, Alameda County, in 1886. In 1891 the Snowflake mine in Napa County began operation. The Red Mountain district of Santa Clara and Stanislaus Counties was first worked in 1899. In 1900 production from the Tulare County deposits began. The state's magnesite production increased from 600 tons for the year 1887 to an average of about 9,000 tons per year for the 10-year period prior to 1915. In 1917, when foreign sources were cut off by World War I, production increased to more than 200,000 tons for the year. The resumption of magnesite importing from Europe following the war, the establishment of sea-water magnesia plants in the late nineteen-thirties and early nineteen-forties, and the near depletion of the richer magnesite deposits, caused the decline of magnesite production in California. During World War II only the Red Mountain deposits were operated and, with the exception of small amounts occasionally recovered from the dumps, no magnesite has been obtained from this area since 1945. A few thousand tons of magnesite from Luning, Nevada, are used to make specialty products each year in Westvaco's Newark plant.

The geologic occurrence of dolomite, and its distribution, production, and application in California, are discussed in a separate section of this volume. The dolomite used at the Moss Landing plant is obtained from a quarry near Natividad, Monterey County. Dolomite deposits near Hollister, San Benito County, supply the plants at Newark and South San Francisco.

Sea water contains the salts magnesium chloride and magnesium sulfate and constitutes an unlimited magnesium reserve. Water from San Francisco Bay, used by the Marine Magnesium Products Corporation, is reported to contain 1.669 grams $MgSO_4$ and 4.176 grams $MgCl_2$ per liter.[9] These values are slightly lower than those of the average sea water (see section on salines).

Bittern is the residual liquid obtained when sea water is solar evaporated for its sodium chloride (common salt) content. Algae that thrive in these liquids color the water red. The following are the principal salts in sea-water bittern and their composition ranges by percent: NaCl, 12.5-16.0; $MgCl_2$, 6.0-8.7; $MgSO_4$, 4.2-6.1; KCl, 1.4-1.9; $MgBr_2$, 0.14-0.20.[10]

Utilization. About 85 percent of all magnesium compounds produced in the United States are marketed as dead-burned magnesia for refractory purposes. A constant demand for magnesia refractories is provided by the steel industry. Each ton of steel produced requires about 5 pounds of refractory magnesia. Other large consumers of refractories are cement plants, and copper and lead refineries. The demand for magnesium compounds by postwar industry has been firm, largely

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[8] Gale, H. S., Magnesite deposits of California and Nevada: U. S. Geol. Survey Bull. 540, pp. 512-516, 1914.

[9] Birch, R. E., and Wicken, O. M., op. cit., p. 529.

[10] Seaton, M. Y., Production and properties of the commercial magnesias: Am. Inst. Min. Met. Eng. Tech. Pub. 1496, 21 pp., July 1942.

because of the intense activity of the steel industry, the chief consumer of magnesia refractories; but the present rate of production of metallic magnesium in the United States is scarcely 3 percent of the rate during 1943, the year of maximum output.

Uses of magnesium commodities produced in California.

Commodity	Uses
Magnesia, dead-burned (including periclase)	Refractories in open-hearth steel furnaces, electric steel furnaces, copper reverberatory furnaces, lead-refining furnaces, and cement kilns.
Magnesia, caustic-calcined	Oxychloride cement for stucco and flooring; fireproof heat-insulating wallboard, for making magnesium metal during war. Catalyst in the manufacture of synthetic rubber.
Basic magnesium carbonate	Insulating materials.
Magnesium carbonate	To prevent salt caking. Insecticides, cosmetics, and pharmaceutical uses.
Magnesium hydroxide	Milk of magnesia, tooth pastes, and other pharmaceuticals.
Magnesite (not produced in California since 1945)	When calcined same applications as magnesia. Epsom salts production by reaction with sulfuric acid.
Magnesium metal (not produced in California since 1946)	Alloyed with aluminum for use in airplanes, tracer bullets, flares, incendiary bombs, flash bulbs, light-weight tools. In non-ferrous metallurgy.
Magnesium chloride	Magnesite stuccos and cement mixtures.

Markets. Much of the magnesia produced in California is marketed in the east, although there is a greater market now for all refractory materials in the west than in pre-war years. This increased outlet is largely a result of the expansion of the steel and cement industries in California and elsewhere in the west. California magnesia producers are, therefore, becoming less dependent on eastern markets where they sell at a disadvantage because of large transportation costs. Some California periclase is exported to Canada where it is electrically fused at Niagara Falls. It is subsequently returned to the U. S. for use in electric furnaces that produce artificial abrasives.[11]

Two brick plants, one of which is part of the Moss Landing operation, and a second in the Los Angeles area, provide the only western sources of refractory bricks. Most of the refractory magnesia produced at Newark is still shipped to eastern consumers.

In January 1949 the price of periclase, 90 percent MgO grade, f.o.b. California plants, was $50.50 per short ton; periclase 93 percent MgO grade was $75.00 per short ton; caustic calcined 85 percent MgO oxychloride grade was $70.00 per short ton.[12] These prices are considerably above pre-war levels when 90 percent MgO grade periclase sold for $35.00 per short ton. Prices were regulated by the government during the war. Imported dead-burned magnesia is subject to a tariff of $11.50 per short ton. This tariff greatly restricts shipments from foreign coun-

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[11] U. S. Tariff Commission, Refractory magnesia, War Changes in Industry Ser., Rept. 12, 1945.

[12] Eng. and Min. Jour., Metal and Mineral Markets, vol. 21, no. 1, New York, McGraw-Hill Publishing Company, Inc., Jan. 1950.

tries. Also foreign brick producers are further hindered in that they are unable to provide the technical service given by U. S. brick makers. But the threat of competition from Austrian refractories is a determining factor in domestic prices.

The various grades of caustic-calcined magnesia and other magnesium compounds produced in California have broad applications, and find their way into world-wide markets. Some caustic-calcined grades are specialty products of a particular composition developed exclusively by a company to satisfy the requirements of a particular consumer. The production data, rate of output, and distribution of these specialties are seldom revealed.

MICA

By Lauren A. Wright

The mica [1] thus far produced in California has been mined intermittently and in relatively small quantity compared with the output of other nonmetallic commodities of the state. A micaceous schist, generally known as sericite schist, has been the principle "mica" mined in California. Sericite is a fine-grained form of the potash-rich mica, muscovite; but many of the rocks known commercially as sericite schist are coarse-grained enough to be true muscovite schist. Nevertheless all such schists are too fine-grained for any uses except those of "scrap mica."

Schists are extensively exposed in several areas of pre-Tertiary rocks in California, and are commonly micaceous enough to be marketed as mica without the removal of other constituent minerals. The production of micaceous schist in California has been somewhat restricted by limited markets but since the end of World War II, its output has markedly increased.

Mica production has been recorded from six properties in the state. A deposit near Ogilby, Imperial County, has been the most continuously operated. A deposit in Ventura County, which was active in 1902-04, was the earliest producer. The known operating periods of the others have been later than 1929. Of these, two were in Inyo County, one in Kern County, and one in Mariposa County.

Sheet mica in small quantities is reported to have been mined from the Ventura County locality,[2] but it has not otherwise been produced commercially in California. In the mid-thirties a small amount of the micaceous mineral vermiculite was mined from a deposit in Riverside County.

Mineralogy and Geology. Of the several minerals that comprise the mica group, muscovite [$H_2KAl_3(SiO_4)_3$] is generally implied in the commercial use of the term "mica." The term also may include other micas such as the magnesium-rich mineral phlogopite, and the iron- and magnesium-rich mineral biotite, but these are marketed in much smaller quantity and as yet are of no commercial significance in California. Sericite, apart from its fineness of grain, is identical with muscovite.

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[1] The term "mica" as used in this section excludes the lithium-bearing mica lepidolite which has been mined in San Diego County and is discussed in the section on lithium in this volume.

[2] Aubury, Lewis E., The structural and industrial materials of California: California Min. Bur. Bull. 38, pp. 337-338, 1906.

The uses of muscovite stem from the following properties: perfect cleavage, very low conductivity of heat and electricity, flexibility, non-inflammability, elasticity, transparency, vitreous lustre, and lubricating properties. Sheet mica, the most useful and valuable commercial type, is relatively flat material that is sufficiently free from structural defects and inclusions and is large enough to be cut into the shapes ordinarily required in electrical apparatus. According to the U. S. Bureau of Mines specifications published during World War II, a 1 by 1 inch square is the smallest acceptable size to which domestic mica can be trimmed.[3]

"Scrap mica" is a commercial term given to mica of such irregular size and quality that it is suitable only for grinding. The micaceous schist mined in California likewise must be ground, and is marketed for uses similar to those of scrap mica.

Sheet mica is found only in bodies of the relatively uncommon igneous rock, pegmatite. Such mica occurs as a constituent of the original body or as a replacement mineral that formed late in the development of the pegmatite. Pegmatitic mica has been found in sheets that measure several feet in maximum dimension; but in the average deposit, sheets from 12 to 18 inches across are rare. Aggregates of mica books, however, commonly occur in shoots tens or hundreds of feet long.

Only a small fraction of the world's known pegmatite bodies contain commercial concentrations of high-quality mica. None in California have yet proven capable of sustained production, although many of them were inspected as possible sources during World War II.[4]

The micaceous schists, such as that schist from which the current mica production in California is obtained, contain mica in small grains and also contain gritty minerals such as quartz and feldspar. This mica cannot, therefore, be used for the same purposes as sheet mica.

The mica schists of commercial interest generally represent shales or acidic volcanic rocks in which the original mineral constituents recrystallized to form a mica-rich rock. Such deposits may form belts that are continuous for several or many miles. The value of a deposit, therefore, does not necessarily depend on size but rather on such factors as percentage of mica in the rock, ease of grinding, transportation costs, and availability of a market.

Localities. The mica property at Mt. Alamo, Ventura County, was active for the 3 years 1902-04, but has since been idle. It has been described as muscovite mica "in a feldspar gangue, between a granite hanging and a mica schist foot wall."[5] A small amount of mica was mined, ground, and marketed for use as a lubricant and as a filler in the manufacture of roofing, wall paper, and rubber. Several hundred pounds of sheet mica in small books was used in washers and electrical insulators.

The property near Ogilby, Imperial County, known as the Micatalc deposit, was first worked in 1929. The sericite schist is obtained from a pre-Cambrian metamorphic formation that contains the Ogilby kyanite deposit.[6] The schist is removed in a quarrying operation, is ground, and is marketed chiefly in the Los Angeles area. It is used as a lubricating

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[3] Gwinn, G. Richards, Strategic mica: U. S. Bur. Mines Inf. Circ. 7258, p. 5, 1943.

[4] For further data on commercial pegmatites in California, see the sections on gem stones, feldspar, and lithium in this bulletin.

[5] Aubury, Lewis E., op. cit., p. 337.

[6] See section on andalusite, kyanite, and sillimanite in this bulletin.

dust for roofing surfaces, as a foundry facing material, and as artificial snow.

The mica produced in Mariposa County was obtained from schistose rocks near White Rock, but much of the product was milled at Le Grand, Fresno County. The production of this property was marketed principally as a roofing-surface lubricant, a plaster constituent, and artificial snow.

The mica schist currently mined in Mono County is in the pyrophyllite- and andalusite-bearing metamorphic belt exposed on the west slope of the White Mountains.[7] Mica and pyrophyllite in nearly adjacent layers are quarried by Huntley Industrial Minerals, Inc. Both are ground at a mill at Laws, and recently the mica has been marketed as a paint extender.

Production records of the California Division of Mines indicate that sericite mica in small amounts was also obtained from a deposit in Kern County, presumably near Randsburg, and from another near Shoshone, Inyo County. These properties were worked in 1936 and 1941, respectively.

The vermiculite in Riverside County was obtained from the Asbestos King mine, about 15 airline miles southeast of Indio. There was no record that any of this material was mined or marketed in quantity.

Mining Methods and Prices. Pegmatitic mica is ordinarily mined by underground methods. The mica schist obtained in California, however, has ordinarily been quarried. The mica schist producers in the state have valued the mined material at about $5 per ton. Market quotations in August 1949 for dry-ground mica f.o.b. mines ranged from $40 to $80 per ton. Prices on sheet mica ranged from 70 cents per pound for 1½ by 2 inch to $4.25 per pound for 6 by 8 inch material.[8]

NITROGEN COMPOUNDS

By William E. Ver Planck, Jr.

Although nitrogen comprises 78 percent of the atmosphere by volume, commercial deposits of nitrogen compounds have been found in abundance only in Chile. Approximately 80 percent of the United States nitrogen supply is obtained from the atmosphere and is fixed by artificial means. Normally the United States imports between 30 and 40 percent of its nitrogen compounds. These include natural sodium nitrate from Chile, cyanamide, ammonium sulfate and ammonium phosphate manufactured in Canada, and minor quantities of other compounds.

Uses. The most important use of nitrogen compounds is for fertilizer. In 1947 the fertilizer used on California farms contained 92,610 tons of nitrogen. Explosives require additional quantities, and during times of war the demand for nitrogen compounds to be used for explosives may exceed the demand for fertilizers. Smaller quantities are consumed by chemical industries and in pulp processing.

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[7] See sections on talc, soapstone, and pyrophyllite, and andalusite, kyanite, and sillimanite.

[8] Markets—trends and prices: Eng. and Min. Jour., vol. 150, no. 8, p. 84, August 1949.

California soils in general are more deficient in nitrogen than in other plant foods. In addition to the nitrogen removed by crops, nitrates are leached from soils, and gaseous nitrogen released by bacterial action is also lost. It is thought that nitrogen must be in the form of nitrate to be available to plants. The nitrogen content of manure and other organic compounds, as well as that of ammonium salts and calcium cyanamide ($CaCN_2$), is, however, readily converted to the nitrate form in the soil by bacterial action. In California most of the nitrogen added to soils is in mixed fertilizers, but large tonnages of liquid ammonia, ammonium sulfate, ammonium nitrate, and sodium nitrate are also used.

Sources. No commercial deposits of natural nitrogen compounds have been found in California, although traces of sodium nitrate have been found in certain playas and in efflorescent deposits throughout the southeastern desert. An exhaustive search of these occurrences, undertaken during World War I and in the immediately following years, failed to disclose commercial deposits.[1] No further work was done during World War II, when there was a shortage of nitrogen compounds.

The present most important source of nitrogen compounds in California is synthetic ammonia produced at three plants in the San Francisco Bay area. Ammonia is synthesized from hydrogen and atmospheric nitrogen in the presence of a suitable catalyst. Two of the plants obtain hydrogen from natural gas, and the third uses hydrogen obtained as a by-product in the manufacture of chlorine. Ammonium salts are produced at these and other plants in the state. A small amount of ammonium sulfate is produced as a by-product of coke manufacture at the Fontana plant of the Kaiser Company.

PEBBLES FOR GRINDING

By L. A. Norman, Jr.

Most of the domestic demand for grinding pebbles is normally met by European imports. The availability of imported pebbles, which are cheaply brought to California as ship ballast, has hindered the growth of a grinding-pebble industry in the state. The first pebbles from California sources were marketed in 1915, when imports were cut off by World War I. To date more than 65,000 tons of grinding pebbles have been obtained from sources in the state. About four-fifths of this output was obtained during the period 1915-18. Since 1924, production of grinding pebbles in California has averaged only a few hundred pounds a year; in 1948 no output was reported. Pebbles from California sources, however, have proved satisfactory as grinding media. In recent years pebbles of the type formerly used for grinding have been employed in certain types of filters.

Geologic Occurrence and Localities. The materials most valued as natural grinding pebbles are hard, dense, relatively fine-grained rocks. These are ordinarily siliceous, and must be unusually resistant to wear and capable of wearing evenly. Flint and quartzite are the most widely used, but other types such as rhyolite, granite, basalt, and various metamorphic rocks have proved satisfactory.

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[1] Noble, L. F., Mansfield, G. R., and others, Nitrate deposits in the Armagosa region, southeastern California: U. S. Geol. Survey Bull. 724, 99 pp., 1922.

Noble, L. F., Nitrate deposits in southeastern California: U. S. Geol. Survey Bull. 820, 108 pp., 1931.

Though pebbles are common as constituents of conglomeratic sedimentary rocks, economic concentrations of pebbles that are suitable as grinding media are relatively rare. In California, grinding pebbles have been produced from beach deposits and from river gravels. At each locality in the state from which such pebbles have been obtained, many rock types are present and it is necessary to sort those pebbles suitable as grinding media.

The deposits in California which have contributed most of the grinding pebbles are along the shoreline between Oceanside and San Diego. The pebbles were originally derived from granitic and metamorphic rocks east of the shore and have become concentrated on the beaches during severe storms.[1] Pebbles in these concentrations ordinarily range from 2 to 7 inches in diameter; all are worn smooth, and many are nearly round.

A small production of selected grinding pebbles has been obtained from stream gravels in Sacramento, Fresno, Siskiyou, and Calaveras Counties. Both the beach and stream deposits constitute potential sources of grinding pebbles. The successful operation of these deposits would depend upon careful sorting by experienced workers, as well as on favorable economic conditions.

The most important world sources of grinding pebbles are the flint deposits of Denmark, Belgium, and France. In these deposits the flint occurs as distinct beds in chalk, and accumulates in beach deposits at the bottoms of chalk cliffs.[2] The principal domestic source of grinding pebbles is near Jasper, Minnesota. Here, quartzite is cut into cubes and artificially rounded.

Utilization. Pebbles are used as grinding media when the material being ground must not be contaminated by iron abraded from iron and steel grinding balls or rods. The feldspar industry is one of the largest users of grinding pebbles; the pebbles are also used extensively to grind chalk, quartz, sand, sandstone, talc, and soapstone. Iron and steel grinding media have replaced the commercial pebbles for many uses because iron contamination has been found to be less detrimental than it was originally believed to be.

For several years the Crystal Silica Company has produced pebbles from beach deposits near Carlsbad, San Diego County. These pebbles are used unsorted, in sizes from half an inch to 2½ inches in diameter. Their principal use is with silica sand in layered water filters. The rounded character, hardness, and toughness of the pebbles make them desirable in this application.

Markets. There was no production of grinding pebbles as such in California during 1948, the small recorded production being used for filter purposes. The output of grinding pebbles in the United States for 1947 amounted to 5,860 short tons, valued at $122,883.[3] Production included both naturally rounded pebbles and artificially rounded cubes. The tonnage of imported grinding pebbles is difficult to determine because such figures are grouped under the customs classification ''flint, flintstones,'' which includes both pebbles and liners. For many years this classification also included pyrophoric alloy ''flints'' for pocket and gas lighters.

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[1] Metcalf, Robert W., Grinding pebbles and tube-mill liners: U. S. Bur. Mines Inf. Cir. 7139, p. 2, 1940.

[2] Metcalf, Robert W., op. cit., pp. 1-2.

[3] Abrasive materials in 1947: U. S. Bur. Mines, Mineral Industrial Surveys, Mineral Market Rept., mms. 1662, 1949.

Importing of pebbles from Denmark and Belgium, discontinued during World War II, was resumed in 1945.[4]

The price of Danish pebbles as quoted June 1949 by a California importer is $46 per short ton, C. I. F. in small lots, sacked, and $41 in bulk, San Francisco.

Mining and Treatment Methods. Naturally rounded pebbles are mined or harvested by simple methods involving the use of little equipment. Beach pebbles are screened or hand picked for sizing and in many instances are not washed. The European pebbles are gathered by hand along the beach, washed with water in large revolving drums, and run over a picking belt to separate different grades of pebbles. The domestic, artificially rounded pebbles are produced by shaping cubes of quarried quartzite and rotating the blocks in drums. In some cases, angular blocks of rock are used, because the corners and edges are quickly worn off with usage.

History of Production. The production of grinding pebbles in California was first recorded in 1915 during World War I.[5] Reduced imports and higher prices of European pebbles resulted in a search for domestic sources. A shipment of pebbles from a gold-dredging operation in Sacramento County was made to one of the Mother Lode gold mines. The San Diego coastal deposits were also worked for the first time during that year. In the following year, selected pebbles were shipped from near Friant in Fresno County. The maximum production of 21,450 tons was recorded for California in 1917, and was followed by a gradual decline. No pebbles were produced in 1948 for grinding purposes. San Diego County has been the only important producing area, although selected pebbles have been mined in Sacramento, Fresno, Siskiyou and Calaveras Counties. The total California production of grinding pebbles from 1915-46, inclusive, totals 65,168 tons, valued at $358,315.

PHOSPHATES

By Lewis T. Braun

Large quantities of phosphate rock and prepared phosphate fertilizers are brought into California, but no commercial source of this commodity has been developed within the state.

Geologic Occurrence. Phosphorus present in the crust of the earth has been involved in a complex geologic cycle, several stages of which are represented by commercial deposits of phosphates.[1] This cycle is started when phosphorus of magmatic origin enters into the composition of igneous-rock minerals, principally apatite ($Ca_4(Ca,F)(PO_4)_3$). A few deposits of apatite occur in sufficient concentrations and quantity to be economic sources of phosphate. Large quantities of apatite are currently being recovered from an alkali syenite on the Kola Peninsula, Russia. In 1942, 2,000,000 metric tons of apatite were mined at this locality.[2]

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[4] Metcalf, Robert W., and Holleman, A. B., Abrasive materials: Minerals Yearbook 1946, pp. 100-101, 1949.

[5] Bradley, Walter W., California mineral production for 1915: California Min. Bur. Bull. 71, pp. 59-60, 1916.

[1] Blackwelder, E., The geologic role of phosphorus: Am. Jour. Sci., 4th ser., vol. 42, pp. 285-298, 1916.

[2] Johnson, B. L., and Tucker, E. M., Phosphate rock: Minerals Yearbook 1947, p. 992, 1949.

The cycle is continued when phosphorus, leached from crystalline rock, enters the soil as phosphoric acid. Much of this phosphoric acid is absorbed by plants, and in turn by animals. Some animals, notably bats, sea fowl, and seals, contribute to guano deposits which are an important source of phosphate. Ultimately, most of the phosphorus reaches the sea and is deposited in marine sediments. The factors involved in marine phosphate deposition are not completely understood. Marine organic agencies undoubtedly play a part, but direct chemical precipitation of phosphate is also believed possible.[3] Marine beds, ranging from slightly phosphatic marls and limestones to phosphate rock containing as much as 90 percent tri-calcium phosphate, have been deposited over large areas. A deposit of this type is represented by the Permian Phosphoria formation which is exposed in portions of Utah, Wyoming, Idaho, and Montana.[4] Concentrations of phosphate rock in this formation are the source of the phosphate processed and consumed in California.

Phosphate rock is composed almost entirely of a carbonated calcium phosphate called collophane. Rogers[5] contends that collophane is an amorphous mineraloid of fairly definite composition; but Frondel[6] believes that collophane is actually a submicrocrystalline variety of apatite. Beds of phosphate rock, depending upon the contained percentage of tri-calcium phosphate, may be commercial sources of phosphate. At the present time phosphate rock containing over 65 percent tri-calcium phosphate is considered workable.

Under humid weathering conditions, calcium carbonate is removed in solution from low-grade phosphatic limestones, and residual deposits of phosphate rock accumulate. The Florida deposits, from which two-thirds of the United States production and almost half the world production are derived, are an example of a residual deposit which is in part redeposited. Surface waters may leach phosphate accumulations and redeposit the phosphate at lower levels, enriching pre-existing deposits or forming new ones. The guano deposits of the Pacific islands have been leached in this manner, and commercial phosphate deposits have been formed in the underlying coral limestone. To complete the phosphorus cycle, marine beds may be elevated and metamorphosed to again form crystalline apatite.

Phosphate rock is difficult to distinguish in the field, but the following simple test is reliable. Place a crystal of ammonium molybdate on the rock and add a drop of nitric acid; a yellow precipitate will form if the rock is a phosphate.

Localities. There has been no production of phosphates in California, and no deposits of possible commercial value have been discovered. At some localities, notably in the western San Gabriel Mountains, igneous

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[3] Mansfield, George R., The role of flourine in phosphate deposition: Am. Jour. Sci., vol. 238, no. 12, pp. 863-879, 1940.

Emery, K. O., and Dietz, R. S., Submarine phosphorite deposits off California and Mexico: California Jour. Mines and Geology, vol. 46, pp. 7-15, 1950.

Dietz, R. S., Emery, K. O., and Shepard, F. P., Phosphorite deposits on the sea floor off southern California: Geol. Soc. America Bull., vol. 53, pp. 815-848, 1942.

Blackwelder, E., op. cit.

[4] Mansfield, G. R., The geography, geology and mineral resources of a part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, 1927.

[5] Rogers, Austin F., Pellet phosphorite from Carmel Valley, Monterey County, California: California Div. Mines Rept. 40, p. 417, 1944.

Rogers, Austin F., Collophane, a much neglected mineral: Am. Jour. Sci., 5th ser., vol. 3, p. 275, 1922.

[6] Frondel, Clifford, Mineralogy of the calcium phosphates in insular phosphate rock: Am. Mineralogist, vol. 28, pp. 215-232, 1943.

rocks are unusually rich in apatite. Nodules and pellets of collophane are found in Teritary marine sediments.[7] The presence of these nodules, together with the fact that phosphatic nodules have continued to form in the ocean off the coast of California [8] indicate that commercial deposits of phosphate rock might possibly be found in the Tertiary sediments of the state.

At the Carmel Valley locality described by Rogers, the phosphate strata occur as two poorly defined beds in Miocene shale. These beds which are about half a mile apart, range from 6 inches to 1 foot in thickness, and are composed of pellets which are possibly micro-coprolites.

Collophane oölites or pellets are rather common in the Miocene sediments of the state, particularly in the Monterey shales, and they have been used for correlation purposes by petroleum geologists. They have been reported from the southern San Joaquin Valley,[9] the Los Angeles Basin,[10] Santa Barbara County, and Monterey County.[11] Collophane has been found in Pliocene sediments near Lomita, Los Angeles County, but Rogers believes they have been reworked from the Monterey.[12] A small deposit of phosphate rock was found in Pleistocene sediments near Big Pine in Inyo County,[13] and minor occurrences have been noted in San Diego [14] and Ventura Counties.[15]

Utilization and Markets. In 1948 the domestic production of phosphate rock was approximately 9,600,000 long tons.[16] About nine-tenths of this amount was used as an agricultural fertilizer. The remaining one-tenth was used in stock and poultry feed, in pig-iron blast furnaces, in refractories, and for other minor purposes. California agriculture alone consumed more than 500,000 tons of commercial fertilizer in 1948. As the majority of commercial fertilizers contain some form of phosphate, the importance of phosphate to the state is evident.

A small amount of phosphorus is essential to the normal growth of most plants. Many soils are lacking in phosphorus, or contain "fixed" phosphorus compounds which are unavailable to the plants. To rectify this situation phosphorus fertilizers are added to soil. Ground phosphate rock is sometimes used, but as it is relatively insoluble, the beneficial effects are not immediately apparent. Therefore, phosphate rock is commonly converted to the water-soluble calcium acid phosphate ($CaH_4P_2O_5$) before it is compounded into fertilizers. The Stauffer Chemical Company operates plants at Richmond, California, and Vernon, California, that are engaged in the manufacture of water soluble phosphate (super phos-

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[7] Rogers, Austin F., Pellet phosphorite from Carmel Valley, Monterey County, California, op. cit.
Galliher, E. Wayne, Collophane from Miocene brown shales of California: Am. Assoc. Petroleum Geologists Bull., vol. 15, pp. 257-269, 1931.

[8] Emery, K. O., and Dietz, R. S., op. cit.

[9] Galliher, E. Wayne, op. cit.

[10] Hoots, H. W., Blount, A. L., and Jones, P. H., Marine oil shale, source of oil in Playa del Ray field, California: Am. Assoc. Petroleum Geologists Bull., vol. 19, p. 180, 1935.

[11] Galliher, E. Wayne, op. cit., p. 266.

[12] Rogers, Austin F., Pellet phosphorite from Carmel Valley, Monterey County, California, op. cit., p. 419.

[13] Tucker, W. B., Los Angeles field division—Inyo County: California Min. Bur. Rept. 22, p. 520, 1926.

[14] Merrill, F. J. H., San Diego County: California Min. Bur. Rept. 14, p. 717, 1916.

[15] Tucker, W. B., Los Angeles field division—Ventura County: California Min. Bur. Rept. 21, p. 242, 1925.

[16] Burr, James A., Potash and phosphate in '48: Min. Cong. Jour., vol. 35, no. 2, p. 117.

phate) from western phosphate rock. Recently the Permanente Metals Corporation, of Permanente, California, marketed a product composed of fused western phosphate rock and California serpentine. This material is soluble in soil acids, and contains an appreciable percentage of available magnesium. At the present time, the Westvaco Chemical Corporation is engaged in the construction of a phosphate plant at Newark, California. Elemental phosphorus, produced at Westvaco's Idaho plant, will be used for the preparation of various phosphate compounds.

Most phosphate rock is produced by open-cut mining, in which extensive use is made of large draglines. When the easily recoverable material is removed, underground mining will become necessary, especially in the western states where the sedimentary deposits are extensively folded and faulted.

Florida phosphate rock containing from 77 to 76 percent tri-calcium phosphate was selling for $7.31 per long ton, f.o.b., Florida, in September 1949. Lower grades brought lower prices, so that material containing from 68 to 66 percent tri-calcium phosphate was selling for $4.61 per long ton.[17]

PUMICE, PUMICITE, AND PERLITE

By Charles W. Chesterman

Commercial production of pumice and pumicite in California was started in 1909 with a production of 50 tons valued at $500. In 1948, California led all other states in the production of pumice and pumicite with a total production of 196,934 tons valued at $1,110,447. The production of expanded perlite, on the other hand, was started in 1945 and only within the past year has it been on a volume basis. Both pumice and expanded perlite have many uses, especially as lightweight aggregates. Because of the tremendous growth of population and industry in California during the past few years, the demand for pumice, pumicite, and expanded perlite is rapidly growing in the field of construction, and in chemical and other industries.

GEOLOGIC OCCURRENCES

Pumice, pumicite, and natural perlite are volcanic glasses, which have formed during the rapid chilling of granitic magmas. Most of them are acidic in composition. They are commonly found together in regions of Tertiary to Recent volcanism which cover wide areas throughout California.

General Geological Features of Pumice Deposits. Pumice is a very cellular acidic glass formed by the rapid expansion of gas bubbles contained within a solidifying magma. Pumice corresponds in composition to rhyolite and most of it is light gray to white in color. Crystals of quartz, feldspar, biotite, and hornblende are locally present.

All of the pumice and pumicite deposits occur in tuffs. Tuffs are pyroclastic rocks formed of detrital material expelled aerially from volcanic vents and deposited upon the land surface or in standing water. Most material making up a tuff ranges from dust-like particles of glass, crystals, and rocks to pea-size fragments of pumice and rock. The dust-

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[17] Eng. and Min. Jour., Metal and Mineral Markets, vol. 20, no. 37, New York, McGraw-Hill Publishing Company, Inc., Sept. 1949.

like particles of pumice are referred to as "pumicite" or volcanic ash; fragments ranging from the size of a pea to half an inch in diameter are called "lump pumice" or "lapilli"; the larger fragments, which may be blocks measuring several feet in diameter, are referred to as "block pumice." The size of pumice fragments commonly has a wide range within an individual deposit and from one deposit to another. Therefore, it is often necessary to crush and screen the pumice in order to obtain a product whose size range falls within workable limits.

Tuffs deposited on dry land lack distinct, uniform layering and sorting. However, tuffs formed in standing water are characterized by uniform layering and commonly contain interbeds of clay, sand, and gravel.

General Geological Features of Perlite Deposits. Perlite is a glassy volcanic rock characterized by "onion-skin" fracture. It contains an appreciable amount of dissolved or chemically combined water, and is capable of breaking down into spherical fragments. Perlite, as well as many other siliceous volcanic glasses, will, upon rapid heating, expand into a frothy, white material that resembles pumice and is of considerable value as a lightweight aggregate in the construction industry. In general, the chemical composition of perlite tends to range from rhyolitic to dacitic; most perlite contains from 3 to 5 percent water. Although much perlite is light gray in color, black, reddish-brown, or even green perlite is occasionally encountered. Phenocrysts of quartz, feldspar, biotite, and hornblende may be present. If they occur in abundance, they render the perlite unusable as a raw material for expanded perlite.

Many of the perlite deposits in California are flows associated with thick sections of volcanic and pyroclastic rocks, such as rhyolite, basalt, andesite, tuffs, breccias, and agglomerates. In most places flows of perlite-bearing volcanic rocks lie in a nearly horizontal position, but in some areas they have been moderately deformed. Individual flows of perlite range in thickness from a few feet to several tens of feet. They commonly cover several square miles. Bodies of perlite rock are also known to occur as domes, dikes, and chilled selvages of basaltic and andesitic intrusions.

DEPOSITS OF PUMICE AND PUMICITE

Although extensive areas in the state are covered by Tertiary and Recent volcanic and pyroclastic rocks,[1] deposits of pumice and pumicite are in general restricted to Tertiary rocks in Amador, El Dorado, Fresno, Humboldt, Imperial, Inyo, Kern, Lassen, Madera, Modoc, Mono, Napa, San Benito, San Bernardino, San Luis Obispo, Santa Barbara, Siskiyou, and Trinity Counties. The bulk of the pumice output in California, however, has been obtained from deposits in Inyo, Mono, Napa, Siskiyou, and Stanislaus Counties.

Amador County. In Amador County, about 5 miles west of Ione, pumicite is being mined for use in the chemical industries. The pumicite is a flat-lying bed 10 to 15 feet thick. It is overlain by sediments of the Mehrten (Miocene and Pliocene?) formation, and underlain by sands, clays, and gravels of the Ione (Eocene) formation.

El Dorado County. Deposits of white to gray pumice and pumicite occur near Placerville and Smiths Flat. The material at both localities

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[1] Jenkins, Olaf P., Geologic map of California, scale 1:500,000, California Div. Mines, 1938.

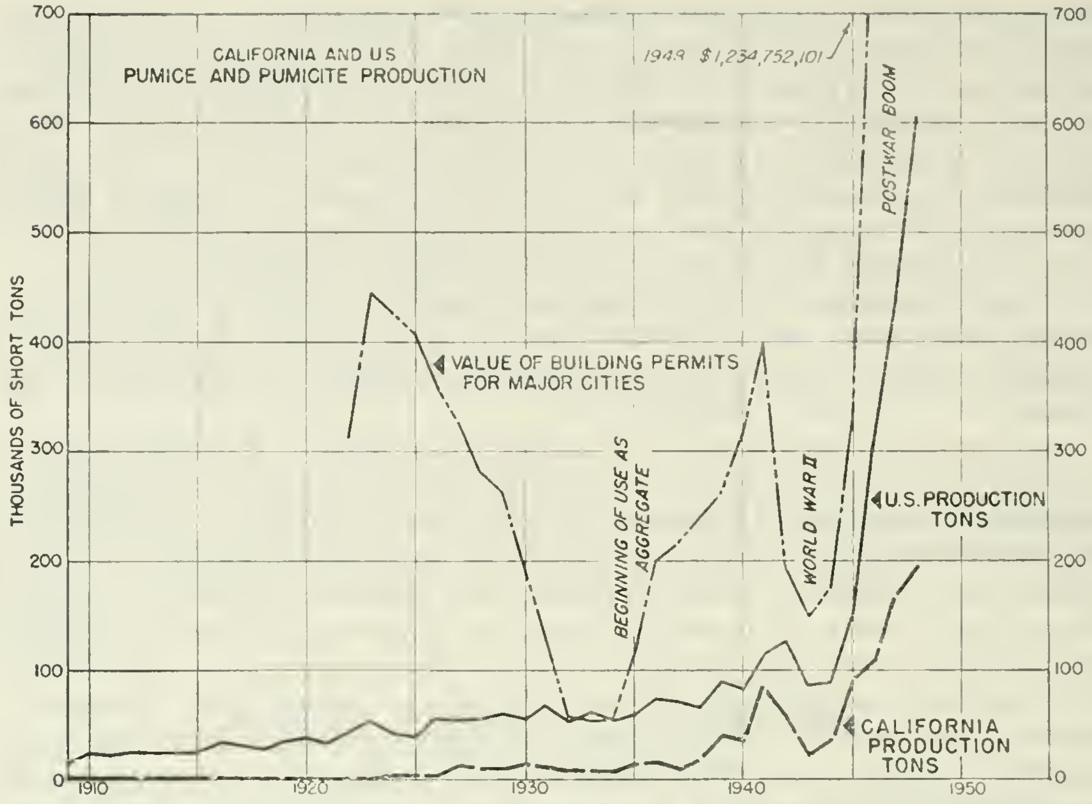

Figure 1. Chart showing production of pumice and pumicite in California (1909-48), compared with United States production (1909-48) and value of building permits issued in California (1922-48).

is rhyolitic tuff which fills ancient river channels. In places the tuff is massive and has been quarried for building stone.[2]

Fresno County. Extensive deposits of pumice and pumicite occur on the south side of the San Joaquin River near Friant. These are a part of the Friant (lower Miocene?) formation,[3] which also contains conglomerates, conglomeratic sandstones, tuffaceous sandstones, and silts. The pumice and pumicite are contained in tuffs and tuffaceous layers and are most abundant in the upper part of the formation. The pumice fragments are subrounded to angular, are as much as 4 inches in diameter, and are white to pale brownish pink.

Humboldt County. A deposit of creamy white pumicite in Humboldt County, on the Weatherby Ranch, about 4 miles south of Elk River, was worked many years ago, but is now idle. The pumicite occurs in a flat-lying bed about 2 feet thick. It is covered by a capping of clay, and is underlain by sedimentary beds which contain clay and lignite. The deposit was mined through a short adit.[4]

Imperial County. In Imperial County, pumice occurs interbedded with Tertiary sediments on the east side of Salton Sea, in the vicinity of Carrizo Creek and Superstition Mountains. The deposits east of Salton Sea were worked for a number of years and produced considerable pumice. Those deposits, located about 9 miles northwest of Calipatria, cover many acres. The pumice is in a flat-lying bed of undetermined

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[2] Logan, C. A., El Dorado County: California Min. Bur. Rept. 22, p. 452, 1926.

[3] MacDonald, G. A., Geology of the western Sierra Nevada between the Kings and San Joaquin Rivers, Fresno County, California: Univ. California, Dept. Geol. Sci. Bull., vol. 26, pp. 262-265, 1941.

[4] Laizure, C. McK, Humboldt County: California Min. Bur. Rept. 21, p. 324, 1925.

thickness and is exposed on a low, rounded hill near the shore of Salton Sea. The pumice ranges in size from dust-like particles to fragments 10 inches in diameter. Approximately 40 percent of the material is lump pumice. Mining is being done by open-cut methods.

Other deposits in Imperial County are in the vicinity of Niland and in an area about 11 miles northwest of Calipatria.[5]

Inyo County. During recent years, considerable pumice for aggregates and abrasive agents has come from deposits in Inyo County. The bulk of the production is obtained from deposits on the west and southwest flanks of the Coso Range. Some of the pumice in this area has been deposited in water, and some on dry land. Most of the present production is from deposits in which the material was deposited on dry land.

The pumice deposited in water is well bedded and contains layers of lump pumice separated by layers of gray, bedded, more or less consolidated sand. The entire sequence ranges from 1 foot to 60 feet in thickness and rests unconformably upon a deeply eroded granitic basement. The pumice fragments range from dust-like particles to lumps 2½ inches in diameter, but most of the material is in fragments three-quarters of an inch in diameter. It is grayish-white in color and contains flakes of brown biotite, as well as grains of quartz and feldspar.

The pumice deposited on dry land lacks well-defined layering, but contains minor amounts of fresh and weathered boulders and fragments of granite, basalt, andesite, rhyolite, and schist, scattered indiscriminately throughout the deposit. The pumice is grayish white. It ranges in size from dust-like particles to lumps 2½ inches in diameter, but most of the pumiceous material is in fragments three-quarters of an inch in diameter. The pumice bed ranges in thickness from 2 to 15 feet and rests unconformably upon a deeply eroded basement of granitic rocks.

Near Shoshone, pumicite occurs in an extensive, flat-lying bed that averages about 12 feet in thickness. It is overlain and underlain by sands and gravels of Pleistocene age. The pumicite is light gray. It is currently being used in the manufacture of cleansers and scouring soaps. A silica-cemented overburden of variable thickness is removed by scrapers and bulldozers, and the pumicite is loaded into trucks with a bucket-loader. Similar pumicite deposits occur to the south and north of Shoshone and in the vicinity of Death Valley Junction.

A pumice deposit about 7 miles north of Big Pine occurs as a bed in gently dipping fanglomerates. It ranges in thickness from 6 to 10 feet. The pumice fragments are angular and range in size from pumicite to lumps as much as 1½ inches in diameter. The pumice is white and contains numerous angular grains of clear quartz, some feldspar, and an occasional plate of biotite.

Pumice also occurs in Hunter Canyon, on the west slope of the White Mountains, about 3 miles northeast of Laws. At this locality, the pumice is also in a bed interstratified with fanglomerate. It is white, and the grain size ranges from pumicite to fragments 2 inches in diameter. Mining is carried on in an open cut.

Kern County. The pumice and pumicite deposits in Kern County are localized around Black Mountain, in the central part of El Paso Mountains. The Cudahy pumicite deposit, now idle after 25 years of continuous production, is in Last Chance Canyon, about 8 miles north of

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[5] Tucker, W. B., Imperial County: California Min. Bur. Rept. 22, p. 280, 1926.

Gypsite, a station on the Owens Valley branch of the Southern Pacific Railroad. The pumicite, also known as volcanic ash and "seismotite," occurs in a bed interstratified with silicified lake-bed sediments of the Ricardo (lower Pliocene) formation. The pumicite bed ranges in thickness from 4 to 9 feet and dips westward at a low angle. It has been traced along its outcrop for a distance of 4 miles and has been developed at intervals along its length by tunnels and open cuts.

Extensive deposits of pumiceous-lapilli tuff, from which pumice for aggregates and abrasives has been mined, also occur in El Paso Mountains. At least 5 deposits have been developed, but of these only one deposit, north of Last Chance Canyon about 3 miles southwest of Black Mountain, has been the principal source of this material. At that locality a pumice bed, which ranges from 10 to 20 feet in thickness, occurs as a lens-like body within a dull-gray, massive tuff that contains numerous angular fragments of andesite, basalt, and rhyolite. The massive tuff is, in turn, overlain and underlain by basalt. The whole section of volcanic flows and pyroclastic rocks dips westward at a moderate angle. The pumice fragments range from pumicite to rounded and subrounded lumps measuring as much as 1 inch in diameter. The pumice is white and moderately well compacted, enough so as to make the use of explosives necessary in quarrying. The deposit has been developed by a series of open cuts along the strike of the bed.

Other deposits of pumice and pumicite, which are idle, occur on the north and south sides of Black Mountain.

Lassen County. Although Lassen County is underlain almost wholly by Tertiary and Quaternary volcanic rocks,[6] the number of known pumice and pumicite deposits is small. A deposit of pumicite crops out over an area of 20 acres about 15 miles southeast of Bieber. It is 20 feet or more in thickness and is overlain by soil. The pumicite is white and the bulk of the material will pass through a 100-mesh screen. The deposit was developed by a 15-foot tunnel. The property is idle.[7]

Madera County. The deposits of pumice and pumicite in Madera County are similar in many respects to those that occur near Friant in Fresno County. They were mined for a number of years and furnished considerable material for abrasives, concrete aggregate, and agricultural insecticides. The pumicite deposits are in flat-lying beds ranging from 25 to 40 feet in thickness.

In general the pumicite is white and is ripple marked. The whitest layer, which ranges from 12 to 15 feet in thickness, is overlain by an off-white layer of pumicite, probably stained by the thin soil covering. Below the white layer are alternating layers of pinkish-brown mud 1 inch to 4 inches thick, and layers of pumicite as much as 12 inches thick.

The pumice and pumicite deposits in Madera County are mined by open pit and bench workings.[8]

Mono County. Extensive deposits of pumice occur in Mono County in the volcanic tableland on the west side of Hamil and Benton Valleys. Although the principal deposits extend from Benton south to the Inyo County line, other deposits of importance are on the west slope of the White Mountains between Sacramento Canyon and Coldwater Canyon.

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[6] Jenkins, O. P., op. cit.

[7] Laizure, C. McK, Lassen County: California Min. Bur. Rept. 17, p. 511, 1920.

[8] Logan, C. A., Personal communication, November 19, 1947.

On the east slope of Blind Springs Hill, about 6 miles south of Benton Station, a bed of pumice 15 to 18 feet thick dips very gently toward the southwest. It is overlain by soft, poorly consolidated, reddish-brown tuff, and underlain by sandy pumiceous rock. Much of the production has come from a single bed of pumice about 12 feet thick. The pumice fragments in this bed are white, angular, and range in size from particles less than one-sixteenth of an inch to lumps 3 inches in diameter. Although the bed is fairly well defined, the pumice fragments within the bed are apparently unsorted. The property was extensively developed by a system of tunnels, but operations ceased several years ago.

Deposits of pumice in the vicinity of Yellow Jacket Springs and in Yellow Jacket Canyon probably contain several million tons. The pumice is in beds exposed on the low hills on both sides of the canyon. The beds range in thickness from 30 to 50 feet and are covered by a thin overburden of pumiceous soil. In general, there are two types of pumice deposits in this area, both of which have been mined extensively. One type, which occurs in thick beds south and southeast of Yellow Jacket Spring, contains well-rounded pumice fragments which range in diameter from an eighth of an inch to 2 inches. They are loosely cemented by fine-grained pumiceous sand. The pumice is pure white to grayish white. It is interbedded with discontinuous lens-like beds of pumiceous sand as much as 6 feet thick. Some of the pumicite is in lens-like bodies that contain numerous well-rounded pebbles of granite, andesite, and schist. Bedding is very well developed throughout the entire section, which dips gently toward the west.

The second type of pumice exposed in the Yellow Jacket Canyon area is made up of beds of angular pumice fragments loosely cemented with a pumiceous sand. In general, the pumice beds range from 8 to 12 feet in thickness. They are overlain by a 1- to 6-foot overburden of sandy pumiceous soil. The pumice is white and the fragments range from one-sixteenth of an inch to 2 inches in diameter. The pumice lies upon a tan, pumiceous, sandy soil layer. The whole section dips toward the east at a low angle. Interbedded with the pumice are lens-like bodies of conglomerate that contain well-rounded pebbles of quartz, granite, rhyolite, and andesite. The pumice in the Yellow Jacket Canyon area is mined by open pit and bench cut methods.

Pumice deposits in Blind Springs Hill Valley, south of Benton, resemble those in the vicinity of Yellow Jacket Canyon that contain the angular pumice fragments. The pumice is white and occurs in beds which dip gently toward the east. It is exposed in numerous cuts and trenches in several widely scattered deposits. Although the reserves of pumice are large in this area, present production is principally from deposits near Benton and in the vicinity of Yellow Jacket Spring.

Deposits on the west flank of the White Mountains between Sacramento and Coldwater Canyons have yielded large amounts of pumice for aggregate and abrasive purposes. The pumice is white and occurs in discontinuous beds that are exposed in and between Sacramento and Coldwater Canyons. The beds range in thickness from 20 to 30 feet, and dip at a moderate angle toward the southwest. They are overlain and underlain by fanglomerate, and the overburden ranges in thickness from 7 to 30 feet.

Mining operations have ceased in the Sacramento Canyon area, but those deposits in the vicinity of Coldwater Canyon are in operation, and produce annually several thousand tons.

The southernmost deposit in Mono County is located on the east edge of the volcanic tableland, about 6 miles north of Laws. The processing plant is located a few hundred yards north of the Inyo County line, but the pumice deposit extends into both counties. The pumice bed, 15 feet in maximum thickness, is overlain by moderately well-consolidated pinkish-brown tuff which ranges in thickness from a few feet to 75 feet. The pumice is underlain by cross-bedded sands and gravels. The pumice is white and is predominately fine-grained, but there is a subordinate amount of lump pumice. The products are used in the manufacture of interior insulating plaster, exterior stucco and insulating plaster, acoustical plaster, and abrasive agents.

Pumice for scouring and griddle blocks is currently being produced from extensive deposits of block pumice near the north end of Mono Craters, Mono County. This material is obtained from a large deposit near the southern border of Panum Crater. It is light gray and occurs in angular and rounded blocks that range from a few inches to 5 feet or more in diameter. Mining is carried on in an open cut where the material is blasted down from the cut walls. The blocks are hand sorted at the pit, loaded into trucks, and hauled to the cutting and trimming plant at Leevining where the finished blocks are made. The bulk of the scouring and griddle blocks produced in the United States are obtained from deposits in this area.

Napa County. In Napa County, commercial pumice is obtained from pumiceous lapilli tuffs exposed along Highway 37 on the west slope of the Howell Range, east of Napa. The tuffs are in beds which dip gently southwest. Most of the mining is confined to areas near the highway. A general section in any deposit would include the following: massive gray pumice at the bottom, overlain by at least 25 feet of pink and gray pumiceous lapilli tuff which, in places, contains considerable pumicite and numerous rounded fragments of black obsidian; the whole being overlain by chocolate-brown soil. In general, the pumice fragments are rather angular and are ordinarily surrounded by thin films of tan clay. They range in size from pumicite to lumps as much as an inch in diameter. Davis has described the Napa County pumice deposits in detail.[9]

Modoc County. Large areas east of Glass Mountain in western Modoc County, are underlain by a thin veneer of pumice. The pumice is grayish white and occurs as a mantle 1 foot to 3 feet thick covering older volcanic rocks. The fragments of pumice are angular and range in size from an eighth of an inch to 1 inch. An overburden of dirty pumice is scraped away and the pumice is mined in open pits. The pumice being mined from the deposits is used extensively in making building blocks.

San Bernardino County. The deposits of pumice in San Bernardino County are northwest of Barstow in the vicinity of Murphys Well and Coolgardie Camp. The pumice occurs in beds of variable thickness in a section composed essentially of flat-lying tuffs which rest upon deeply eroded granite, and are overlain by a thick flow of dark-gray perlite and buff rhyolite. Most of the pumice is obtained from a tuff bed about 40

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[9] Davis, F. F., Mines and mineral resources of Napa County, California: California Jour. Mines and Geology, vol. 44, pp. 172-176, 1948.

feet thick, which has been exposed and explored in several widely spaced cuts.

San Francisco County. In San Francisco County, pumicite or volcanic ash, as it was formerly called, was mined from a deposit in the Merced (upper Pliocene) formation south of San Francisco. Mining operations, however, ceased in 1923 when a golf course was constructed at the site of the deposit. This material was used in the manufacture of cleansing compounds.[10]

San Luis Obispo County. San Luis Obispo County contains several deposits of pumicite. A deposit near Adelaida, which was worked for the first time in 1880, occurs as a bed about 6 feet thick. Other deposits contain pumicite in flat-lying tuff beds 20 feet or more in thickness. In places the pumicite beds strike toward the northeast and dip steeply toward the northwest. They are as much as 50 feet thick and have a thin overburden. The properties are idle.

Siskiyou County. Very extensive deposits of pumice occur in eastern Siskiyou County in the vicinity of Medicine Lake and Glass Mountain. The pumice is grayish-white and occurs in a blanket-like deposit which ranges from 4 to 60 feet in thickness and covers older lava flows. The deposit is composed of fragments of pumice that range from dust particles to large bombs measuring 15 inches in diameter. The average fragment size is about three-quarters of an inch. Scattered through the pumice blanket are angular fragments of red and black basaltic cinder, black obsidian, and gray andesite and rhyolite. Although the first pumice to be mined from this area came from deposits on Pumice Stone Mountain, a few miles west of Medicine Lake, all of the present activity is near the north edge of Glass Mountain where several large pit operations are being carried on successfully.

On the top of Glass Mountain block pumice was mined and sawed into scouring blocks. The pumice is medium gray in color and occurs in blocks several feet or more in diameter that make up the frothy crust of the Glass Mountain obsidian flow.

Trinity County. In Trinity County pumicite occurs in the Minersville district, about 35 miles northwest of Redding. None of the properties are operating.

DEPOSITS OF PERLITE

Deposits of expansible perlite are widely scattered throughout California, particularly in Inyo, Kern, Lake, Lassen, Modoc, Mono, Napa, Riverside, San Bernardino, Siskiyou, and Sonoma Counties.

Inyo County. In Inyo County, the largest of the known deposits of perlite are in the Coso Range; near the base of the Sierra Nevada, 7 miles south of Big Pine; and in the Dublin Hills a few miles west of Shoshone. The Coso Range deposits are domes and are associated with extensive beds of pumice. The deposit south of Big Pine is large and forms a prominent hill which stands up above the alluvial apron of the Sierra Nevada. The deposits west of Shoshone are flows associated with opalized tuffs and breccias and flows of rhyolite.

Other perlite deposits in Inyo County are at Sheephead Mountain and Salisbury Pass, 10 miles southwest of Shoshone, and at the southwest end of Death Valley.

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[10] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), p. 22, 1914.

Production of crude perlite in Inyo County has been almost wholly confined to the deposit south of Big Pine, but a few tons were obtained from the Shoshone area for experimental purposes.

Kern County. All of the perlite deposits in Kern County are in the desert area in the eastern part of the county. A deposit at the southernmost end of the Sierra Nevada, about 7 miles northeast of Monolith, contains flows of perlite associated with perlite breccia, rhyolite flows, tuffs, domes of dacite, and lacustrine (lower Pliocene) sedimentary rocks. Several perlite deposits in El Paso Mountains, 5 miles north of Saltdale, have been explored and produced a small tonnage of material for experimental purposes. Here, the perlite occurs as irregular and lenticular bodies within flows of rhyolite; and also as flows that directly overlie extensive flows of basalt. In places the perlite is overlain by tuffs and lake bed (lower Pliocene) sediments.

Lake County. Southwest and east of Clear Lake, Lake County, an extensive flow of black, pumiceous obsidian rests directly upon an older olivine dacite.[11] A light-colored, pumiceous portion of the obsidian expands into an exceedingly light, white, fluffy material.

Lassen and Modoc Counties. In Lassen County, deposits of perlite are exposed on the west flank of Hot Springs Peak, 4 miles northeast of Wendel. The perlite is gray, and occurs with andesitic agglomerates and dikes of rhyolite.

Perlite deposits in Modoc County are apparently confined to the northern part of the Warner Range, in the vicinity of Sugar Hill and Fandango Peak. On Sugar Hill, perlite flows are associated with lithoidal rhyolite and olivine basalt. The perlite is light gray. Near the surface of the flow, thin lenticular bodies of fractured smoky black obsidian are contained in a matrix of soft, friable perlite. On the west flank of Fandango Peak, a perlite flow rests directly upon rhyolite and is overlain by basalt. In the immediate vicinity of Fandango Peak, the perlite flow is at least 100 feet thick; but 2 miles south of Fandango Peak, the flow is thinner and becomes markedly pumiceous.

Mono County. Although Tertiary and Recent volcanic rocks cover extensive areas in southeastern Mono County, deposits of perlite appear to be restricted to rhyolitic rocks located to the north and east of Casa Diablo Hot Spring. The perlite is dark gray and forms irregular lenslike bodies in tuff and brownish-pink rhyolite.

Sonoma County. At several localities in Sonoma County deposits of dark to light-gray perlite occur in the Sonoma (Pliocene) volcanics. A few miles southeast of St. Helena, perlite occurs in flows which range in thickness from a few feet to tens of feet, and which are folded into northwest-trending anticlines and synclines. The perlite lies upon tuffs and conglomerate, and is overlain by a light-gray, vesicular dacite. Perlite also occurs in a deposit 2 miles southeast of Bismark Knob and in several small deposits 5 miles east of Napa.[12]

Riverside County. Riverside County is largely underlain by pre-Cambrian and pre-Cretaceous metamorphic rocks intruded by Jurassic acid granitic rocks. In the Little Chuckwalla Mountains, about 38 miles southwest of Blythe, Tertiary volcanic rocks contain extensive deposits of perlite.

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[11] Anderson, C. A., Volcanic history of Clear Lake area, California: Geol. Soc. America Bull., vol. 47, p. 654, 1936.

[12] Davis, F. F., op. cit., p. 171.

San Bernardino County. San Bernardino County contains the largest number of perlite deposits of any county in the state. Most of these deposits are in either Miocene or undifferentiated Tertiary volcanic rocks. Deposits in the low hills a few miles north of Pilot Knob in the northwestern corner of the county are part of a series of volcanic rocks, which include tuffs, agglomerates, breccias, flows of basalt and adesite, and dikes of basalt. The whole section dips gently westward and rests upon tuffaceous lacustrine sediments. The perlite flows are variable in thickness, ranging from a few tens of feet to well over 100 feet.

Deposits of perlite similar to those near Pilot Knob are exposed in the vicinity of Black Canyon, 18 miles south of Pilot Knob, and 4 miles north of Coolgardie Camp. Perlite flows are associated with basalt flows, tuffs, agglomerates, breccias, and lake beds, presumably Rosamond. At a deposit 4 miles north of Coolgardie Camp, perlite rests upon pumiceous lapilli tuff which is being mined for its pumice content.

Large deposits of expansible-grade perlite are well exposed in the Miocene volcanic rocks 6 miles north of Klondyke and 12 miles north of Bagdad, stations on the Santa Fe Railroad. The perlite is in gently to steeply dipping flows which, in several places, are as much as 100 feet thick. They are overlain and underlain mostly by tuffs and pumiceous rhyolite which, near the perlite, are perlitic.

On Clipper Mountain, about 18 miles northeast of Amboy, lenticular bodies of perlite occur in a thick section of volcanic and pyroclastic rocks which overlies sandy lacustrine tuffs. The perlite, which is overlain by platy rhyolite, overlies a brecciated perlite which, in turn, overlies well-bedded tuffs and sandstones. The entire section rests upon a basement of coarse-grained granite.

Extensive deposits of perlite are exposed in the Turtle Mountains, about 30 miles southwest of Needles. The Turtle Mountains are composed mostly of undifferentiated Tertiary volcanic rocks and tuffs which rest upon Archean metamorphics and granite.[13] The volcanic rocks dip steeply toward the west and include flows of rhyolite, basalt, and andesite. The tuffs in some places are well bedded and appear to be subaqueous in origin. Other tuffs are poorly bedded and are subaerial. The perlite occurs as flows which range from a few feet to several tens of feet in thickness. They are closely associated with tuffs and pumiceous perlitic rhyolite, which, near the perlite, contain rounded and angular fragments of perlite. Dikes of andesite and basalt commonly cut the other volcanic rocks and tuffs.

Irregular lens-shaped deposits of perlite occur in the Newberry Mountains, 6 miles south of Newberry.

Siskiyou County. On Mount Hoffman, in the Medicine Lake Highland, eastern Siskiyou County, large deposits of perlitic rhyolite occur upon basalts and andesites. The entire sequence is apparently a dome built up by successive outpourings of viscous perlitic rhyolites, each flow ranging from 50 to 150 feet in thickness.[14]

Sonoma County. A large portion of the southern part of Sonoma County is underlain by Pliocene volcanic rocks, tuffs, and agglomerates.

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[13] Thompson, D. G., The Mojave Desert region: U. S. Geol. Survey Water-Supply Paper 578, p. 738, 1929.

[14] Anderson, C. A., Volcanoes of the Medicine Lake Highland, California: Univ. California, Dept. Geol. Sci. Bull., vol. 25, p. 374, 1941.

Scattered throughout these volcanics are bodies of perlite, one of which is being mined. Perlite deposits, about 4 miles east of Glen Ellen, are lenticular bodies in rhyolitic tuffs which are underlain by silicified rhyolitic tuff and overlain by riebeckite rhyolite. The entire series dips gently toward the west.

On the Annadel Farms, near Lawndale, there are two distinct types of perlite; one contains rounded fragments of black obsidian; the other contains no obsidian.

The first type is well exposed in an old, abandoned railroad cut 3 miles northwest of Lawndale. The perlite is light gray. It occurs as lenticular bodies of variable thickness and length in a platy rhyolite whose flow banding and prominent jointing strike in a northward direction and dip steeply east. In places the perlite is highly brecciated and contains, besides rounded fragments of black obsidian, considerable clay, formed through alteration of the perlite.

The second type of perlite on the Annadel Farms is well exposed at a quarry, where it overlies rhyolite which is quarried for flagstone. The perlite is a flow of variable thickness that dips gently toward the east. It is overlain by tuff and basalt.

Large deposits of medium-gray perlite occur on the south flank of Taylor Mountain, about three-quarters of a mile north of the Steuben school. The perlite contains appreciable amounts of quartz, feldspar, and biotite, and forms flows of variable thickness and length overlying rhyolitic tuffs which, in turn, are overlain and underlain by flows of dark, platy, massive andesite.

UTILIZATION

Pumicite and pumice were used by the Romans in cement in constructing aqueducts, harbor installations, the Pantheon, and other classical structures. Pumice and pumicite are currently being used principally as lightweight aggregates in the construction industry, where they are mixed with lime mortar, portland cement, or other binders. Certain pumicites and pumices are used as ingredients in pozzuolanic cements. Appreciable quantities are marketed as abrasive materials in scouring compounds and cleansers. Minor uses of pumicite include fillers in paints. paper, and rubber; as an insecticide carrier in the chemical industry; and as a filter aid and absorbent material.

Expanded perlite, on the other hand, has found its greatest use in the making of plaster aggregates, which include ready mixed acoustical plaster, ready mixed fibered hardwall plaster, and noncombustible acoustical tile. It is also used as dry-kiln insulation, as roofing insulation, and as a filter aid and abrasive. Minor amounts are used as a carrier in the chemical industry, as chicken litter, and as a soil conditioner.

The principal use for pumice in California is as a lightweight aggregate in concrete and plaster. Expanded perlite, on the other hand, is essentially synthetic pumice whose properties can be modified to suit any specific use. The processing of perlite is involved and expensive, but it can successfully compete with pumice in many of its uses.

MARKETS

California in 1948 produced a total of 196,934 tons of pumice and pumicite worth $1,110,447. This represents an increase in tonnage of 16 percent over the 1947 production of 169,037 tons, and an increase of 131 percent over the previous peak year of 1941. California is the largest producer of pumice and pumicite in the United States. This is well emphasized by the fact that in 1948 California produced 32 percent of the national annual tonnage. The national production of pumice and pumicite jumped from 442,552 tons in 1947 to 607,746 tons in 1948, an increase of 37 percent.

The annual production of perlite in California is small, but the industry has barely started. In 1948, shipments of crude perlite were made from properties in Napa and Inyo Counties to expanding plants at Campbell and Los Angeles, and to plants in the east. There are several perlite-expanding plants in California, but they receive the bulk of their crude perlite from deposits outside the state.

The average value for California pumice and pumicite in 1948 was $5.63 per ton at the property. Crude perlite is usually sold from $5 to $7 per ton, f.o.b. car, producers shipping point. The price for expanded perlite at the plant where it is expanded ranges from 18½ to 33⅓ cents per cubic foot in the bag.[15]

PYRITES

By Charles W. Chesterman

For many years, California has been one of the four principal pyrite-producing states and in 1946 made the third largest production. The chief use of pyrites is in the manufacture of sulfuric acid, which is being used in oil refining, the chemical industries, and manufacture of fertilizer.

Geology and Deposits. Pyrites is a general name applied to a group of iron-sulfide minerals including pyrite (FeS_2), marcasite (FeS_2), and pyrrhotite ($Fe_{1-x}S$, with x between 0 and 0.2).[1] Both pyrite and marcasite, when pure, contain 46.55 percent iron and 53.45 percent sulfur. Pyrrhotite, on the other hand, contains between 58 and 61 percent iron and 36 to 41 percent sulfur.

Pyrites, especially pyrite, are widespread in their occurrence. Pyrite is found as scattered grains in practically all types of rocks, as a gangue mineral in many kinds of metallic ore deposits, and as large irregular masses in igneous, metamorphic, and sedimentary rocks. It is most common as a gangue mineral in metallic ore deposits, but these are rarely mined for their pyrite. It is only when pyrite occurs in massive deposits that it can be commercially mined for its sulfur content.

Marcasite is not as stable as pyrite. It occurs most commonly with sphalerite, galena, and pyrite as replacement deposits in limestone. Pyrrhotite is commonly associated with chalcopyrite, pyrite, magnetite, pentlandite, and molybdenite. It commonly occurs in large deposits in such igneous rocks as gabbro, norite, or peridotite (as is the case of the large nickeliferous pyrrhotite deposits at Sudbury, Ontario), or in metamorphic rocks with molybdenite, or in veins, or in pegmatites.

Of these iron-sulfide minerals, pyrite has by far the greatest commercial importance. It has been produced commercially for its sulfur content in Alameda and Shasta Counties.

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[15] Mineral Information Service, vol. 1, no. 4, California Div. Mines, September 1948.

[1] Palache, C., Berman, H., and Frondel, C., Dana's system of mineralogy, 7th ed., vol. 1, p. 233, 1944.

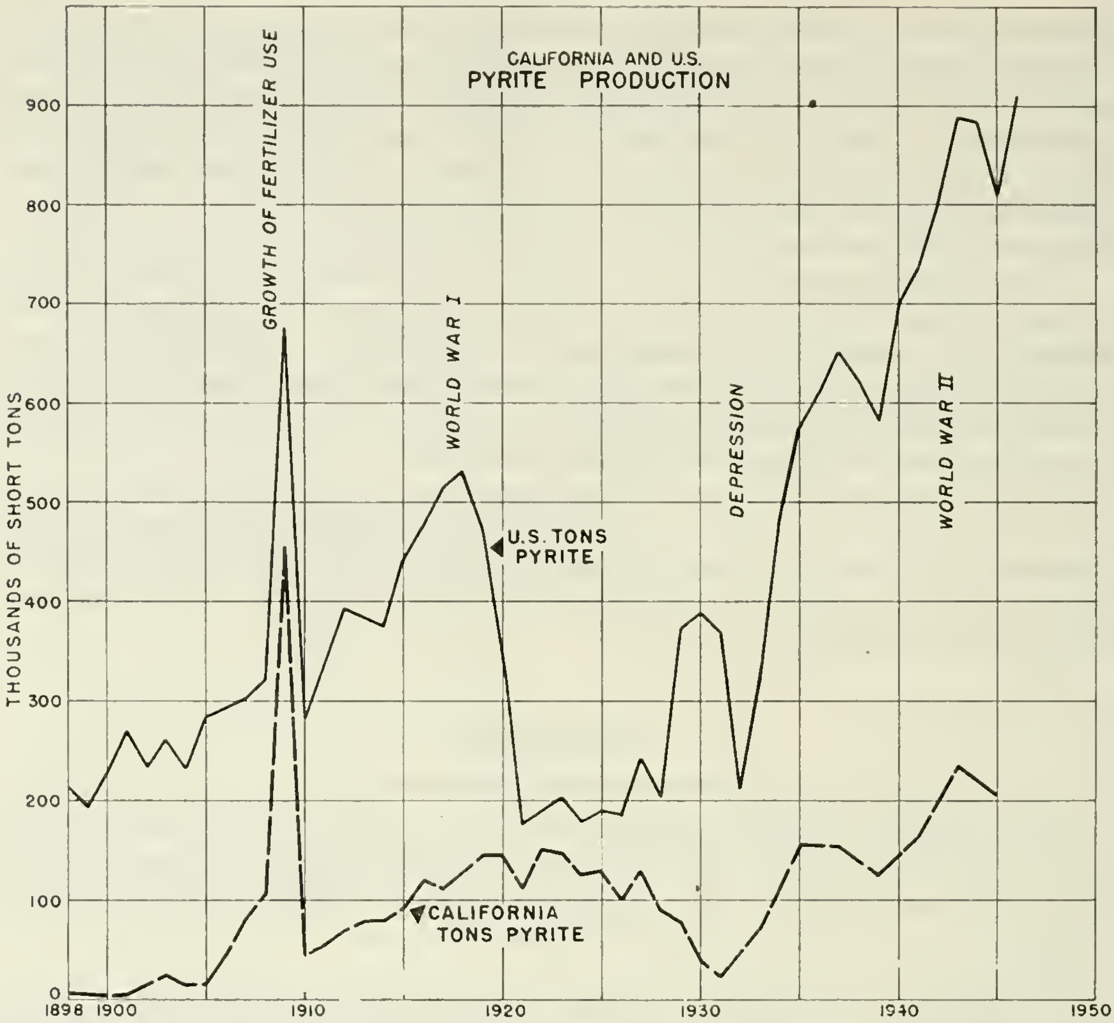

FIGURE 1. Chart showing production of pyrite in California and the United States, 1898-1946. Two-year averages are used on the California curve, 1931-46.

Pyrrhotite, on the other hand, has been mined in Orange, San Diego, and Trinity Counties for its valuable-metal content and not for its sulfur.

In California, very large deposits of massive and disseminated pyrite occur in the Hornet mine of the Mountain Copper Company, Shasta County. The pyritic bodies are irregular, tabular masses that measure as much as 1200 feet in length, 300 feet in width, and 300 feet in depth. They contain more than a million tons of ore that contains small amounts of copper and zinc, $2 per ton in gold and silver, and 50 percent sulfur. The pyrite occurs as replacement deposits in intrusive bodies of alaskite porphyry which are more or less altered in the vicinity of the ore deposits.[2]

Aside from Shasta County, whose mines have had the largest production of pyrite in California, Alameda County is probably the only other county from which there has been any appreciable pyrite production. In Alameda County, the pyrite deposits occurred as massive, irregular bodies in the Leona rhyolite, which is Tertiary in age and forms a

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[2] Graton, L. C., The occurrence of copper in Shasta County, California: U. S. Geol. Survey Bull. 430, pp. 71-111, 1907.
Diller, J. S., U. S. Geol. Survey Geol. Atlas, Redding folio (no. 138), 1906.

narrow belt along the west front of the Berkeley Hills. The pyrite averaged about 47 percent sulfur. It carried some gold and approximately 1 percent copper.[3]

During the first World War, several large deposits of pyrite were discovered in the Dillon Creek area, western Siskiyou County. The pyrite occurs as irregular replacement bodies and as disseminated grains in a metamorphosed andesite. The deposits are covered for the most part by an extensive gossan. They carry small amounts of gold, zinc, and copper. These deposits are now being developed.

Massive sulfide bodies composed essentially of pyrrhotite with minor amounts of chalcopyrite and pyrite are found in Orange, San Diego, and Trinity Counties. At the Friday mine in the Julian mining district, San Diego County, an irregular mass of nickel-bearing pyrrhotite is at the contact between gabbro and fine-grained mica schist. This deposit contains on the average 2.0 percent nickel and from 0.5 to 1.0 percent copper.[4]

A large body of massive sulfide occurs at Island Mountain, on the Eel River, southwestern Trinity County. The deposit, which consists essentially of pyrrhotite, is an irregular body in sedimentary rocks that are probably part of the Franciscan formation. It carries 3.5 percent copper, 1.5 ounces of silver, and $2.00 gold per ton of sulfides. Minor amounts of zinc and nickel are also present.[5] There has been no production from this deposit for a number of years.

Utilization. Pyrites have for many years been a source of raw material for the manufacture of sulfuric acid,[6] which is used extensively in the chemical industry, in oil refining, and in the manufacture of fertilizer. In the manufacture of sulfuric acid from pyrites, a deep reddish cinder of iron oxide is produced as a by-product. A limited amount of this cinder is used in some eastern steel plants. Small amounts are also used in the manufacture of paints, and as a source of iron in portland cement.

Large tonnages of pyrite, chalcopyrite, and other auriferous concentrates, when treated for their metal content, yield some sulfuric acid as a by-product.

Production. The bulk of the pyrites consumed in the manufacture of sulfuric acid in California comes from the Hornet mine, Shasta County. Formerly, operations in Alameda County, not far from the center of Oakland, supplied substantial amounts of pyrite which were converted into sulfuric acid in plants in the San Francisco Bay area. Mining at the Alameda deposits ceased many years ago.

Commercial production of pyrites in California commenced in 1898 with the production of 6,000 tons of pyrite. Production has been continuous, but it has fluctuated greatly since then. Maximum production was reached in 1908 when a total of 457,867 tons of pyrite was mined. This tremendous increase in production over previous years was undoubtedly due to the development of fertilizer plants in the San Francisco Bay area.

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[3] Laizure, C. McK, Alameda County: California Div. Mines and Mining Rept. 25, p. 440, 1929.
Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), p. 23, 1914.

[4] Creasey, S. C., Geology and nickel mineralization of the Julian-Cuyamaca area, San Diego County, California: California Div. Mines Rept. 42, pp. 25-27, 1946.

[5] Averill, C. V., Mineral resources of Trinity County: California Div. Mines Rept. 33, p. 23, 1941.

[6] See sections on sulfur and sulfuric acid in this bulletin.

Total production in California from 1910 to 1945 was 3,319,264 short tons of pyrites, valued at $12,525,023. Total production of pyrites for the same period for the United States was 16,309,230 short tons, valued at $53,540,308.

The nominal price of Spanish pyrites, considering sulfur content at 48 percent, is quoted at 14 to 16 cents per unit of sulfur delivered to east coast ports.[7]

QUARTZ CRYSTAL

By Lauren A. Wright

Previous to World War II, large, transparent crystals of quartz were used mostly as semiprecious gems, and were of minor commercial importance. The piezoelectric properties of quartz have been known for many years; as early as 1921 it was recognized that especially prepared plates of high-quality quartz could be used as radio-frequency controls in vacuum-tube oscillators. But not until the entry of the United States into World War II did the demand for these plates become large.[1]

The United States has depended almost entirely upon foreign sources for its commercial supply of quartz crystal; this material is still being stock piled as a mineral essential for national defense. As yet no suitable, easily obtainable substitute has been found.

During World War II, approximately 5 tons of usable quartz crystal were mined in the United States. Nearly nine-tenths of this output was produced in Arkansas. Deposits in California contributed a few hundred pounds of usable material.

Placer deposits south of Mokelumne Hill, Calaveras County, yielded most of the California output; but radio-quality quartz is also reported to have been obtained from two other deposits in the state, one in Tulare County, the other in San Diego County. No production of quartz crystal has been recorded in California since 1944.

Mineralogy and Geologic Occurrence. Quartz, one of the world's most abundant and widespread minerals, rarely occurs in crystals suited to the manufacture of oscillator plates. Such crystals must be large, transparent, untwinned, and inclusion-free.

> "The dimensions of operating crystal plates, and manufacturing methods have limited the physical size of quartz crystals heretofore used to a minimum of 100 grams by weight having a length parallel to the vertical crystallographic axis of at least 2 inches and a diameter, perpendicular to the vertical crystallographic axis, of at least 1 inch. Quartz of this size must exhibit at least one identifiable crystallographic face for economical use, although crystals over 2,000 grams can be economically processed whether 'faced' or not." [2]

Nearly all of the world's quartz crystal is mined in Brazil. The productive Brazilian deposits are mostly veins, pipes, pockets, or blanket deposits of milky quartz in which transparent crystal is a very subordinate constituent.[3]

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[7] Eng. and Min. Jour., Metal and Mineral Markets, vol. 21, no. 1. New York, McGraw-Hill Publishing Company, Inc., Jan. 1950.

[1] A thorough discussion of the geology and crystallography of quartz crystal and the technology of oscillator-plate production is contained in a thirteen-paper symposium in the American Mineralogist, vol. 30, nos. 5 and 6, May-June, 1945.

[2] Waesche, Hugh H., Piezoelectric crystalline quartz still needed: Mining and Metallurgy, vol. 29, no. 493, pp. 22-23, 1948.

[3] Stoiber, R. E., Tolman, C., and Butler, R. D., Geology of quartz crystal deposits: Am. Mineralogist, vol. 30, pp. 245-268, 1945.

In California, quartz crystals of radio grade have been found in the auriferous gravels of the Sierra Nevada, in hydrothermal veins, principally the auriferous veins of the Sierran foothills; and in pegmatites.[4]

Localities. Most of the state's quartz-crystal output has been obtained from auriferous gravels at Chili Gulch, 2½ miles south of Mokelumne Hill, Calaveras County.[5] Quartz crystal was first mined here in 1897, but the property is believed to have been previously worked for gold. The early quartz-crystal production, obtained in 1897-98, was used as ornamental material.[6] The property was reopened for a short period during World War I and the quartz crystal was marketed "for scientific purposes."[7] Operations were resumed during the period 1942-44 and the area yielded several thousand pounds of quartz crystal, but only a small fraction of this was of radio grade.

The crystal-bearing gravels, which are possibly upper Eocene in age, fill a stream channel cut in slates and greenstones. Most of the crystals were found within 6 feet of bedrock. They are believed to have been transported but a short distance from a source of the bedrock, but no crystals have been found in place.

The crystals occur both singly and in clusters and are virtually unworn. The average weight of single crystals is probably between 20 and 30 pounds; one is reported to have weighed more than a ton.

The crystals have been removed by underground methods from two old drift mines, the Green Mountain (Calaveras Crystal or McSorley) mine and the Rough Diamond (Rough Diamond Crystal) mine. In 1944 the combined reserves of these properties were estimated by Durrell[8] at about 17,000 pounds, of which approximately 5 percent would be radio grade; but they are now believed to be nearly exhausted.

In 1943 a few crystals of radio-grade quartz were obtained from a small hydrothermal vein at the Mable II mine 2 miles east of Camp Nelson, Tulare County. The crystals at this deposit range from 1 inch to 3 inches in diameter, but most of them contain bubbles.

During World War II a small amount of radio-grade quartz was also obtained from the Senpe pegmatite near Pala, San Diego County.[9]

Other deposits considered by Durrell to be possible sources of usable quartz crystal include a quartz vein in serpentine on the Gorman Ranch, ¾ mile from Michigan Bluff, Placer County; placer deposits between Dry Creek and Big Indiana Creek, northeast of Fiddletown, Amador County; auriferous quartz veins at Our Chance mine, 7 miles northeast of Mariposa, and at Giles Ranch near Hornitos, both in Mariposa County; and a pegmatite on the east side of Greenhorn Mountain, 5 miles west of Kernville, Kern County. Of these, Durrell[10] considers the Fiddletown placers to be the most promising of the known quartz crystal deposits in California. It is believed, however, that none of these properties are capable of sustained production, except under conditions of unusual necessity.

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[4] Dr. Cordell Durrell has kindly contributed many of the data in this section. Dr. Durrell, as a member of the U. S. Geological Survey, was the geologist in charge of quartz-crystal investigations in California and Nevada during World War II.

[5] Durrell, Cordell, Geology of the quartz-crystal mines near Mokelumne Hill, Calaveras County, California: California Div. Mines Rept. 40, pp. 423-433, 1944.

[6] Kunz, G. F., Gems, jewelers' materials, and ornamental stones of California: California Min. Bur. Bull. 37, pp. 64-66, 1905.

[7] Durrell, Cordell, op. cit., p. 423.

[8] Durrell, Cordell, op. cit., pp. 432-433.

[9] Jahns, R. H., and Wright, L. A., The pegmatites of the gem and lithium districts, San Diego County, California: California Div. Mines Bull., in press.

[10] Durrell, Cordell, personal communication 1950.

Prices and Markets. Since 1945 no quartz crystal from domestic sources has been marketed. The purchase price of imported material has been in the general range of $1.50 to $37 per pound, depending upon quality.

SALINES

By William E. Ver Planck, Jr.

The salines include those soluble salts normally found dissolved in sea water or brine. Deposits of saline materials are found only in arid regions, unless they have been buried and protected from solution. Some salines are recovered from natural precipitates; others by treatment of brine or sea water. Salines of commercial importance in California include borates, bromides, calcium chloride, gypsum, iodine, potassium salts, sodium chloride (salt), sodium carbonate, and sodium sulfate. Lithium, strontium, and magnesium compounds may be conveniently included with the salines because the present important occurrences in California are as salines. In 1946 the value of the salines produced in California amounted to $22,699,416, or about 13 percent of the value of all mineral commodities, exclusive of petroleum.

Source of the Soluble Salts. Many of the soluble salts are derived from the weathering of rock-forming minerals. Carbonic acid formed by carbon dioxide of the atmosphere dissolved in ground water attacks feldspars and produces carbonates. Although the processes are probably complex, representative reactions can be conveniently pictured as follows:

$$KAlSi_3O_8 \text{ (orthoclase)} + H_2CO_3 \longrightarrow K_2CO_3 + \text{kaolinite}$$

$$NaAlSi_3O_8 \cdot CaAl_2Si_2O_8 \text{ (plagioclase)} + H_2CO_3 \longrightarrow Na_2CO_3 + CaCO_3 + \text{kaolinite}$$

Similarly the weathering of sulfides, particularly pyrite, produces soluble sulfates.

The weathering of rocks does not produce the quantity of borates and chlorides found in some waters. These salines are, however, commonly associated with volcanism, and it is thought that most of the borates and part of the chlorides originated in hot springs or were leached from volcanic ejecta. Another source of chlorides is the sea water that has been trapped in the interstices of marine sediments.

These soluble products dissolve in ground water and accumulate in rivers. The mineral content of rivers varies both in character and amount. In California the Santa Maria River at Santa Maria contains 2412 parts per million of dissolved solids, but the Merced River at Merced Falls contains only 65 parts per million.[1] In the California rivers the relative abundance of bicarbonates and sulfates varies. In most of them bicarbonates predominate, but some are high in sulfates. The chloride concentration is always lower than the bicarbonate or sulfate concentration. In a similar way, the relative abundance of magnesium, calcium, and sodium salts varies from river to river. The proportion of magnesium salts in California rivers is always less than that of calcium or sodium, but the number of rivers high in sodium is about equal to the number high in calcium.

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[1] Van Winkle, Walton, and Eaton, F. M., The quality of the surface waters of California: U. S. Geol. Survey Water-Supply Paper 237, pp. 134, 135, 1910.

Average dissolved salt content of river water throughout the world [*]

	Percent dissolved solids
CO_3	35.15
SO_4	12.14
Cl	5.68
NO_3	0.90
Ca	20.39
Mg	3.41
Na	5.79
K	2.12
$(Fe, Al)_2O_3$	2.75
SiO_2	11.67
	100.00

[*] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 770, p. 119, 1924.

Groundwater finds its way to the sea or to undrained basins where the dissolved salts accumulate. The salinity of the sea varies, but the following analysis of the solids may be taken as representative.[2]

Analysis of total dissolved solids in sea water

	Percent dissolved solids
Cl	55.292
Br	0.188
SO_4	7.692
CO_3	0.207
Na	30.593
K	1.106
Ca	1.197
Mg	3.725

Total dissolved solids; 3.3% of sea water

In comparing sea water with average river water two facts are apparent. The first fact is that the relative abundance of the dissolved salts is reversed. In average river water calcium bicarbonate is the most abundant salt; and sulfates, chlorides, and sodium salts are of minor importance. In sea water, however, sodium chloride is far more abundant than other salts. The second fact is that the chloride concentration in the sea is in excess of sodium, while in rivers the opposite is true. When river water reaches the sea, calcium carbonate is precipitated or withdrawn by organisms, and sulfates probably precipitate also. No simple explanation, however, is apparent for the excess of chloride over sodium in the sea.

Saline Lakes. Although the sea contains small quantities of all the salines, many of them are produced commercially only from saline lakes. Saline lakes may be arms of the sea that have been cut off, or they may be undrained basins in regions where evaporation approximates the amount of water flowing in. The California playas belong to the latter class, but the prehistoric body of water that occupied the Salton basin is believed to have been an extension of the Gulf of California.[3]

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[2] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 770, p. 127, 1924.

[3] Brown, J. S., The Salton Sea region, California: U. S. Geol. Survey Water-Supply Paper 497, pp. 58-60, 1923.

Chemically no two saline lakes are exactly alike. All of them, however, fall into one of two groups, the chloride type or the volcanic type.[4] Clarke[5] has classified them into seven types based on the proportion of salts present.

The chloride type resembles sea water and is characteristic of isolated arms of the sea. Such waters are also found in undrained basins in regions of sedimentary rocks. Waters of the volcanic type, which are found in basins where volcanic rocks are abundant, contain carbonates, sulfates, and borates, and a smaller proportion of chlorides.

The Precipitation of Salts. In 1849 Usiglio[6] evaporated water from the Mediterranean Sea to determine the order of precipitation of sea salts. When the volume of the water had been reduced one-half, calcium carbonate, magnesium carbonate, and ferric oxide began to precipitate. At 20 percent of the original volume these materials were completely removed from solution, and gypsum began to form. When the volume reached 15 percent of the original, most of the gypsum had precipitated, but some continued to come out down to 3 percent. Salt began to form in quantity when the volume was reduced to 10 percent, and continued to 1.6 percent. Magnesium sulfate and magnesium chloride precipitated in the same range, but the greater part of these salts formed after most of the salt had come out of solution. The remaining liquid was a bittern containing magnesium, potassium, and sodium chloride, sodium bromide, and magnesium sulfate.

The precipitation of a salt is greatly influenced by temperature, concentration, and the presence of other salts. This fact is particularly noticeable with those salts which remain in the bittern. Not only will there be a different order of precipitation for different brines, but the order may be different for the same brine if conditions vary. The behavior of systems of mixed salts was studied by Van 't Hoff[7] who worked with the Stassfurt salts. Similar studies have been made of Searles Lake brine by chemists of the American Potash and Chemical Corporation.[8]

Origin of Saline Deposits. Saline deposits form by the evaporation of saline water in arid regions. They are forming today in the deserts of southeastern California, and similar deposits are known to have formed in the geologic past.

Capillary action draws groundwater upward, and dissolved salts may be precipitated at or close to the surface. Efflorescent crusts of calcium carbonate are called caliche. Black alkali and white alkali soils contain efflorescent deposits of sodium carbonate and sodium sulfate respectively. Much of the gypsum produced in California has come from the San Joaquin Valley where earthy deposits of gypsum and silt called gypsite form surface layers as much as 3 feet thick.[9]

Most of the salines, however, have precipitated in bodies of water. Dry lakes or playas, which are common in the California deserts, usually are filled almost entirely with mud and are covered with an efflorescent

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[4] Lindgren, Waldemar, Mineral deposits, 4th ed., p. 316, New York, McGraw-Hill Book Company, 1936.

[5] Clarke, F. W., op. cit., pp. 175-180.

[6] Clarke, F. W., op. cit., pp. 219-221.

[7] Grabau, A. W., Principles of salt deposition, 1st ed., pp. 61-75, New York, McGraw-Hill Book Co., 1920.

[8] Teeple, J. E., The industrial development of Searles Lake brine, 182 pp., New York, Chemical Catalog Co., 1929.

[9] See Gypsum in this bulletin.

crust of mixed salts. Some playas, however, contain beds of a pure salt or mixed salts.

A single cycle of evaporation would account for the salines found in the playas, but the thick deposits of pure salt or gypsum such as the Avawatz Mountains salt deposit in San Bernardino County and the Fish Creek Mountains gypsum deposit in Imperial County cannot be explained as simply. No completely satisfactory theory for the origin of this type of deposit has yet been proposed.

Owens and Searles Lake. Searles Lake, one of the most interesting saline deposits in California, is a playa in which water stands above the surface only after heavy rains. Owens Lake, now a playa, was a saline lake until its inflow was decreased with the completion of the Los Angeles aqueduct in 1913. These are two of a series of dry lakes which during Pleistocene time had an integrated drainage.[10] Owens Lake had an outlet to Searles Lake through Indian Wells Valley and Salt Wells Valley. Searles Lake in turn emptied into Panamint Valley and probably Death Valley.

Today Searles Lake is a vast flat of mud and sand mixed with salts; in its center is a porous crystal body averaging 70 feet thick and having an area of 13 square miles.

Average composition of brine filling interstices of crystal body, Searles Lake *

Salt	*Percent by Weight*
$NaCl$	16.50
Na_2SO_4	6.82
KCl	4.82
Na_2CO_3	4.80
$Na_2B_4O_7$	1.51
Na_3PO_4	0.155
$NaBr$	0.109
$LiCl$	0.021
Na_2S	0.020
As_2O_3	0.019
CaO	0.0022
Fe_2O_3 and Al_2O_3	0.0020
NH_3	0.0018
NaI	0.0014
Sb_2O_3	0.0006
Total solids	34.782

* Teeple, J. E., The industrial development of Searles Lake brines, p. 18, New York, Chemical Catalog Co., 1929.

The composition of the crystal body is not uniform. In one bore hole near the center of the lake the following salts were encountered:[11]

0-15 ft.	Halite: ($NaCl$)
15-20 ft.	Halite, hanksite, ($9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCl$) and trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$)
20-25 ft.	Mostly hanksite
25-40 ft.	Hanksite, halite, trona, and borax ($Na_2B_4O_7 \cdot 10H_2O$)
40-75 ft.	Hanksite, halite, trona, borax, and glaserite ($3K_2SO_4 \cdot Na_2SO_4$)

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[10] Gale, H. S., Salines in the Owens, Searles, and Panamint basins, southeastern California: U. S. Geol. Survey Bull. 580, pp. 251-323, 1913.

[11] Teeple, J. E., op. cit., pp. 15-16.

In other holes the same salts are found, but in different proportions. Neither the brine nor the crystal body contains calcium or magnesium salts, although they are present in the underlying mud.

About 1946 a second crystal body was discovered 12 to 15 feet below the main body. The lower body, which has an average thickness of 25 feet, is lower in potash but higher in sodium carbonate than the upper body. The brine from the lower body has the following average composition:[11a]

	Percent
Na_2CO_3 (equivalent)	6.78
$Na_2B_4O_7$ (total B_2O_3)	1.96
Na_2SO_4	6.56
NaCl	15.51
KCl	2.94
Na_2S	0.38

Salt Wells Valley and Indian Wells Valley are basins filled with alluvium. It is thought that they acted as settling basins and provided clear water to Searles Lake.

Owens Lake[12] before its desiccation contained principally carbonates, sulfates, and chlorides. The lake bed now contains a crystal body similar to that at Searles Lake but with a maximum thickness of only 9 feet. Both the crystal body and the brine are higher in soda content and lower in potash content than Searles Lake.

Commercial Operations. The commodities obtained from Owens Lake include trona, soda ash, and borax, while from Searles Lake these and the following are produced: salt cake, potash, bromine, and lithium salt.

The history of production of salines from Owens Lake can be divided into three more or less overlapping phases.[13] The first began with the completion of the Carson and Colorado Railroad in 1884 and continued until about 1921. The Inyo Development Company evaporated lake brine in solar pans and precipitated trona, which was calcined to a rather poor grade of soda ash. This process was discontinued when the lake brine became so concentrated that the trona precipitated in the lake.

During the second phase, which lasted from 1915-37, sodium bicarbonate was made by passing carbon dioxide from lime kilns through towers containing lake brine. Sodium bicarbonate was calcined to soda ash, and the CO_2 was recycled. The Natural Soda Products Company, the California Alkali Company, and the Inyo Chemical Company used this process.

The third and present phase began in 1935 when the Kuhnert process began to supplant older methods. At present the Pittsburgh Plate Glass Company, the Natural Soda Products Company, and the Permanente Metals Corporation are processing Owens Lake brine.

The Pittsburgh Plate Glass Company [14] obtains brine from wells sunk in the crystal body. It is concentrated in solar pans and then carbonated

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[11a] May, F. H., and Leonardi, M. L., The utilization of natural brines from California dry lakes for the manufacture of soda ash by carbonation: unpublished paper presented at Los Angeles Fall Meeting of A.I.M.E., Oct. 20, 1949.

[12] Dub, G. D., Owens Lake—source of sodium minerals: Am. Inst. Min. Met. Eng. Tech. Pub. 2235, 1947.

[13] Dub, G. D., op. cit., p. 7.

[14] Dub, G. D., op. cit., pp. 10-11.
Tucker, W. B., and Sampson, R. J., Mineral resources of Inyo County: California Div. Mines Rept. 34, p. 499, 1938.

at 100°-110°F in carbonating towers with boiler flue gas compressed to 30 pounds per square inch pressure. Under these conditions trona precipitates. This material is partly dewatered in a thickener tank and further dried with centrifuges. The trona is then dried with steam dryers and packed for sale, or it may be roasted to soda ash in a Hereshoff furnace.

Borax is recovered from the thickener overflow by chilling. The resulting sludge is dewatered on an Oliver filter and the liquor returned to the lake. The filter cake is redissolved, treated chemically and filtered before the refined borax is again precipitated by chilling.

Production of salines at Searles Lake began about 1873 when J. W. and D. S. Searles began producing borax by leaching the crust of the playas and recrystallizing the salts. Five years later this operation was incorporated as the San Bernardino Borax Mining Company. Borax was produced until 1895 when the Pacific Coast Borax Company, which owned rich colemanite deposits in Death Valley, bought the property.

About 1905 or 1906 the California Trona Company was incorporated for the purpose of producing trona both from the lake brine and from the reefs of trona on the east side of the lake. This operation failed in 1909. A period of claim jumping and confused title followed, out of which the successor to the California Trona Company emerged with patented claims on 3320 acres in the north-central part of the lake.[15]

The presence of potash was announced to the press in March 1912 after E. E. Free of the United States Bureau of Soils and H. S. Gale of the United States Geological Survey had collected and analyzed representative brine samples.[16] This announcement and a report [17] prepared and published by the United States Geological Survey created a lively interest in Searles Lake. The American Trona Company, which acquired the assets of the California Trona Company, completed a plant in 1914, which was to recover sodium carbonate and potassium chloride. The operation was unsuccessful.

The acute shortage of potash during World War I created renewed interest in Searles Lake. Among several companies which built experimental plants, two became producers. One, owned jointly by the Pacific Coast Borax Company and the Solvay Process Company, operated at Borosolvay from 1916-20. The second, the American Potash and Chemical Corporation, acquired the old plant at Trona.

A low grade of potash was produced at high cost. After foreign potash was available again, potash from Searles Lake was no longer salable. The Borosolvay plant was shut down, but the American Potash and Chemical Company initiated an intensive research program and is now a major producer of chemicals. Early in World War II, it was discovered that over 90 percent of the capital stock was owned by German nationals. These shares were seized by the Alien Property Custodian which held them during the remainder of the war. On March 27, 1946,

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[15] Teeple, J. E., op. cit., pp. 20-25.

[16] Gale, H. S., Searles Lake; Mineral resources U. S., 1912, pt. 2, pp. 884-885, 1913.

[17] Gale, H. S., Salines in the Owens, Searles, and Panamint basins, southeastern California: op. cit., pp. 251-323.

the company was returned to private control. The seized shares were bought by a group of investment bankers for resale.[18]

The American Potash and Chemical Corporation [19] produces sodium sulfate, soda ash, borax, boric acid, potassium sulfate, potassium chloride, lithium salt, bromine, and bromine salts. Brine from wells sunk in the upper crystal body of the lake together with recycled mother liquor, is concentrated in triple-effect evaporators. During the evaporation, common salt, burkeite ($2Na_2SO_4 \cdot Na_2CO_3$), and dilithium sodium phosphate are precipitated, withdrawn from the evaporators, and washed free of mother liquor. By means of hydraulic classification these salts are separated into a coarse fraction high in salt and a finer fraction containing most of the burkeite and lithium salt. This fraction is leached free of salt in the burkeite digestion process and dissolved in water. The lithium salt, which remains in suspension, is removed by flotation, dewatered, dried, and packed in bags. The burkeite solution is sent to the sulfate process where, after cooling, Glauber's salt is precipitated, filtered out, and converted to salt cake or desiccated sodium sulfate.

The filtrate from the sulfate process is sent to the carbonate process where salt is added to precipitate any remaining sulfate as burkeite. Salt is removed from this solution by chilling, and further chilling precipitates sal soda ($Na_2CO_3 \cdot 10H_2O$), which after dehydration is sold as soda ash.

The hot liquor from the main evaporators is chilled, and the potassium chloride which precipitates is removed. Further cooling precipitates borax, which is recrystallized and sold as refined borax. Some of this is fused to make the patented product Pyrobar, anhydrous crystalline borax. In addition some borax is treated with sulfuric acid to form boric acid.

Some of the potassium chloride is dried and sold for agricultural purposes. Moist potassium chloride is treated with burkeite to produce potassium sulfate. Chemical-grade potassium chloride is made by dissolving and recrystallizing moist potassium chloride after removing the bromine in Kubierschky towers.[20] Liquid bromine, sodium bromide, potassium bromide, and ammonium bromide are produced in the bromide plant. A plant to produce soda ash from the lower brine was constructed in 1947 and 1948. Carbonation with boiler flue gas is practiced.

The West End Chemical Company produces soda ash and borax. Lake brine is concentrated by solar evaporation, clarified in settling tanks, and carbonated with carbon dioxide obtained by calcining dolomite. The sodium bicarbonate obtained is filtered and calcined. Borax is obtained by evaporating and chilling the filtrate.[21]

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[18] Chem. Eng., vol. 53, no. 4, p. 155, April 1946.

[19] Teeple, J. E., op. cit., pp. 56-63.

Gale, W. A., Lithium from Searles Lake: Chem. Industries, vol. 57, no. 3, p. 445, September 1945.

Searles Lake chemicals: Chem. Met. Eng., vol. 52, no. 10, pp. 134-137, October 1945.

Bradley, W. W., Flow-sheet of American Potash and Chemical Corporation at Searles Lake, California: California Div. Mines Rept. 41, p. 362, 1945.

Hou, T. P., Manufacture of soda: 2d ed., pp. 25-30, New York, Reinhold Publishing Corp., 1942.

[20] See Bromine in this bulletin.

[21] Tucker, W. B., and Sampson, R. J., Mineral resources of San Bernardino County: California Div. Mines Rept. 39, p. 542, 1943.

BORON

The world's largest known reserves of boron minerals are in southeastern California. In recent years these deposits have supplied not only the needs of the United States but over nine-tenths of the world's requirements. Metallic boron has very limited uses, but borax and boric acid are exceeded by few chemicals in the extent of their application.

Mineralogy. At present borax and kernite are the most important commercial boron-bearing minerals in California. There are also large reserves of colemanite and less easily obtainable reserves of ulexite, both of which were formerly mined. Ulexite is the boron mineral mined in Chile and Argentina, whereas priceite is mined in Turkey, sassolite in Italy, and boracite in Germany.

Of the many minerals containing boron, by far the most important commercially are the borates. The sodium borates form a series characterized by different amounts of water of hydration. Borax ($Na_2B_4O_7 \cdot 10H_2O$) forms milky white translucent to opaque crystals, many of which are large. It is readily soluble in water. On exposure to dry air borax dehydrates to tincalconite ($Na_2B_4O_7 \cdot 5H_2O$), a finely crystalline dull white powder. Kernite commonly forms in masses of prismatic crystals which when pure are glassy clear. Three well-developed cleavages cause it to break into characteristic splintery fragments. Kernite will hydrate to tincalconite.

The calcium borates form a series which include inyoite ($Ca_2B_6O_{11} \cdot 13H_2O$), meyerhofferite ($Ca_2B_6O_{11} \cdot 7H_2O$), colemanite ($Ca_2B_6O_{11} \cdot 5H_2O$), and priceite ($Ca_5B_{12}O_{23} \cdot 9H_2O$). Colemanite occurs in white to gray prismatic crystals or granular masses. It is transparent to translucent and is but slightly soluble in water.

The sodium-calcium borates include ulexite ($NaCaB_5O_9 \cdot 8H_2O$) and probertite ($NaCaB_5O_9 \cdot 5H_2O$). Ulexite forms rounded masses, called cottonballs, made up of loosely knit fine acicular crystals. Less commonly it occurs as a dense cross-fibered vein filling cutting other borates. Probertite forms radiating needle-like crystals associated with ulexite.

Other boron minerals are howlite ($H_5Ca_2B_5SiO_{14}$) which, although associated with colemanite, is not an ore because of its silica content, and boracite ($Mg_6Cl_2B_{14}O_{26}$). Tourmaline and other complex borosilicates are found in igneous rocks.

Geologic Occurrence. Boron is believed to be a constituent of magmas. Not only do igneous rocks contain borosilicates but boric acid is present in hot springs and is deposited near solfataras. Boron has been detected in sea water, and the boracite present in the Stassfurt deposits is thought to have been derived from evaporated sea water. Some saline lakes, particularly those in regions of recent volcanic activity, have a high borate content; examples of these in California include Mono Lake, Owens Lake, and Borax Lake.

Certain playas of the desert regions of California contain borates in the saline crusts which form during dry weather. Borax and cottonball ulexite with some tincalconite are found mixed with varying proportions of salt, other sodium salts, and mud. Many of these borate crusts are but a few inches thick, but they form again when removed.

The borates of saline lakes and playas are thought to have been derived in part from hot springs associated with Tertiary volcanism and in part from material leached from older borate deposits. Some such explanation is necessary to account for the absence of magnesium and potash in most of these deposits.

Colemanite with a minor proportion of ulexite is found in folded Tertiary sediments. The borates form beds or irregular masses within a bed and are associated with lake beds, tuffs, and lava flows. Deposits of this type in the Death Valley area are at Furnace Creek and in the Amargosa Valley of Inyo County; others are in the Calico Mountains near Daggett, San Bernardino County, near Lang in Los Angeles County, and in the northeastern part of Ventura County. Several theories have sought to explain the origin of the colemanite deposits, but it is now generally believed that they are Tertiary playas which have been elevated and folded. Drainage having been thus provided, the sodium borate was leached from the original ulexite leaving the insoluble calcium borate, colemanite.[22]

Playa deposits are known in all the deserts of the world, and colemanite beds of the type described occur in Nevada as well as in California; but the thick beds of crystalline borax and kernite near Kramer are unique. These deposits, described by Gale,[23] lie in a basin containing Tertiary rocks of the Kosamond middle Miocene and Ricardo upper Miocene formations.

The Ricardo formation in the Kramer area is divisible into three distinct units which from bottom to top are (1) the Saddleback basalt flows, (2) the borate-bearing lake beds, and (3) the post-borate conglomerate. The lake beds are in turn composed of three recognizable parts. The lowermost 30 to 50 feet is known as the footwall shale, a dark greenish to black slate containing seams or veinlets of ulexite and howlite. This unit, when present, directly overlies the basalt flows. The principal borate deposits are contained in the blue shale, or middle lake bed unit, which is 200 to 250 feet thick and is characteristically clayey and thinly laminated. The uppermost lake bed unit is the green shale, 30 to 50 feet of green thinly bedded micaceous shale which contains no borates.

Nodular masses of colemanite and ulexite are widely, though sporadically, distributed in the blue shale unit throughout the Kramer area; but the sodium borate bodies, which are of much greater commercial importance, underlie a $1\frac{1}{2}$- by $\frac{1}{2}$-mile area in the center of the basin. These are characteristically tabular beds or layers of borax and kernite, somewhat interlayered with clayey sediments, which reach a maximum thickness of 250 feet. The borate beds are preserved in a synclinal structure that has been modified by subsidiary folding and minor faulting. The borate deposits now lie at depths of from 300 to 1000 feet beneath the surface.

The Kramer borates, Gale believes,[24] were derived from volcanic gases or water that issued during and immediately after the extrusion of the Saddleback basalt. Relatively pure borax was precipitated by the chilling of the hot saturated solution of mixed salts which accumulated in the basin. The borax was later covered by clays and in part altered to kernite. The presence of small amounts of realgar and stibnite suggest

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[22] Foshag, W. F., The origin of the colemanite deposits of California: Econ. Geology, vol. 16, pp. 199-214, 1921.

[23] Gale, H. S., Geology of the Kramer borate district, Kern County, California: California Div. Mines Rept. 42, pp. 325-378, 1946.

[24] Gale, H. S., op. cit., pp. 376, 377.

that the alteration may have been caused by heat. Ripple marks in the sediments interbedded with borax, and an egg shell found in it, suggest the borates formed in shallow water.

The brines of Searles and Owens Lakes supply a substantial part of the California borax production. Searles and Owens Lakes are remnants of a drainage system which in Pleistocene time extended from the Sierra toward Death Valley. Their waters now contain unusual concentrations of borates as well as alkali carbonates, sulfates, and chlorides.

Localities and History of Production. Three sources, the Kramer deposit, Owens Lake, and Searles Lake, now contribute nearly all of the borates produced in California. A colemanite-ulexite deposit near Shoshone, Inyo County, has a small annual production. At various times all the other types of deposits have been important borate sources, but each has become noncommercial with the successive discovery of richer deposits. The history of the industry in the western United States can thus be divided into four periods. The first began in 1864 with the discovery of borax in Borax Lake and Hachinhama Lake, Lake County, California.[25] Borax crystals were recovered from the mud of these lakes and from lake water which was evaporated in small pans. In 1872 the recovery of ulexite and borax from playa surfaces put an end to the Lake County operations. Playas scattered over eastern California, Nevada, and Oregon were worked. Among these were Searles Lake, Danby Lake, and Death Valley in California, and Rhodes Marsh in Nevada. The laborious process of scraping up and refining the borate material has been described by Hanks.[26]

These operations terminated about 1887 when the colemanite beds were discovered in folded Tertiary sediments of the Calico Mountains near Daggett. Similar deposits were soon discovered near Furnace Creek, Death Valley; near Lang, Los Angeles County; and in the northeastern part of Ventura County; all were worked by underground methods.[27] The fourth and present period began in 1926 when the production in quantity of borates from the Kramer deposit made the colemanite deposits uneconomic. Borax was first recovered from Owens Lake in 1926 and in significant quantities beginning in 1931. At Searles Lake production began in 1919.

Borates in the Kramer district were discovered accidentally in 1912 or 1913 by Dr. J. K. Suckow who was drilling a water well. It was not until 1925, however, that the sodium borates were noted in a drill hole, and another year passed before the deposit was reached by a shaft sunk by the Pacific Coast Borax Company. A new sodium borate was recognized, and its analysis was reported by the laboratory of the Pacific Coast Borax Company at Wilmington, California, on August 18, 1926.[28] The new mineral was named rasorite after Clarence R. Rasor, field engineer of the United States Borax Company.[29]

In the meantime W. T. Schaller obtained some samples of the new mineral and determined its properties. Not knowing that the borax com-

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[25] Hanks, H. G., Report on the borax deposits of California and Nevada: California Min. Bur. Rept. 3, pt. 2, pp. 15-26, 1883.

[26] Hanks, H. G., op. cit., pp. 40-42.

[27] Keyes, C. R., Borax deposits of the United States: Am. Inst. Min. Met. Eng. Trans., vol. 40, pp. 674-710, 1909.

[28] Gale, H. S., op. cit., p. 331.

[29] Palmer, L. H., Kernite or rasorite?: Eng. and Min. Jour., vol. 123, p. 494, 1927.

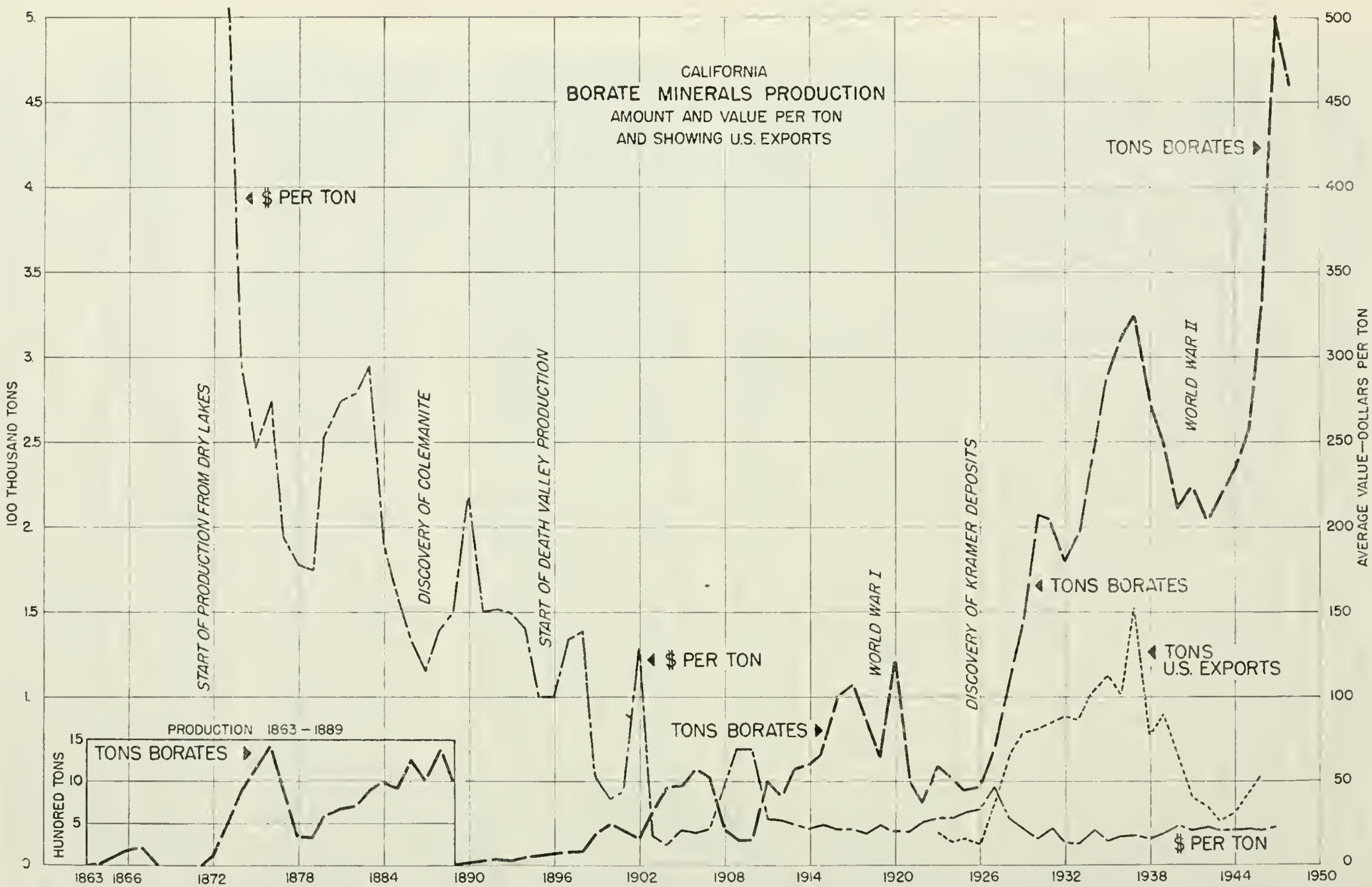

FIGURE 1. Chart showing amount and average price of borates produced in California, 1863-1948, and United States exports of borax, 1923-48. Production figures after 1921 recalculated to 40 percent anhydrous boric acid equivalent.

pany was already using the name rasorite, Dr. Schaller called the new mineral kernite,[30] the name that is most used today.

Utilization. The uses of elemental boron are very limited. The addition of a small quantity of boron to medium-carbon steel increases the hardenability. The NE (national emergency) steels developed during World War II contain boron. For hardenability 0.003 percent of boron may be substituted for 0.18 percent silicon, 0.79 percent nickel, 0.27 percent chromium, 0.12 percent manganese, or 0.23 percent molybdenum.[31]

Boron in the form of boron alloy steel has been used as an absorber of neutrons in the uranium-graphite piles used in producing the radioactive element plutonium.[32]

In agriculture boron is one of the micronutrient elements of soils. The functions of these elements are imperfectly understood, but it is known that plants require a very small but definite amount of boron—about 1/10 part per million. Too much is harmful, and a concentration of 1 part per million is toxic.

The uses of borax and boric acid, on the other hand, are numerous. In normal times the greatest single use is for coating steel. The glass industry requires additional large tonnages both as a flux and in the manufacture of borax glass. Important quantities are used as a flux in metallurgy and in the manufacture of borax soap. Among the long list of minor uses are its employment in paint, food preserving, drugs, tanning, wood preserving, cosmetics, paper, and insecticides.

During World War II the shortage of steel for civilian uses caused not only a decrease in the output of enameled steel, but an enormous increase in the output of glass containers which require borax in their manufacture. With the end of the war, a trend to normal conditions began.

Markets. There is no tariff on imports of crude borates. Small quantities of refined borax are normally imported, but the tonnage of crude borates imported is negligible. Exports were greatly curtailed during World War II but are rising again.

The price of technical borax, 99½ percent, remained constant at $41.50 a ton during the war. It rose to $44.50 a ton in 1946.

BROMINE

Bromine and bromine compounds are produced in California at a rate of about 1000 tons a year. Present sources in the state are Westvaco Chlorine Products Corporation at Newark, Alameda County, which produces bromine from salt-works bittern, and the American Potash and Chemical Corporation which obtains it from the brine of Searles Lake, San Bernardino County. Bromine is a by-product at both plants. California's output is about 2 percent of the national total, the principal source of which is a sea-water treating plant at Freeport, Texas.

Geology and Mineralogy. Bromine, one of the halogens, is intermediate in chemical properties between chlorine and iodine. It is usually associated with the salines. At atmospheric pressure and normal temperature bromine is a heavy, reddish-brown liquid which is very volatile and

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[30] Schaller, W. T., Kernite, a new sodium borate: Am. Mineralogist, vol. 12, no. 1, pp. 24, 25, Jan. 1927.

[31] Corbett, R. B., and Williams, A. J., Effects of boron in steel: U. S. Bur. Mines Rept. Inv. 3816, June 1945.

[32] Nighman, C. E., Boron: Minerals Yearbook 1945, p. 818, 1947.

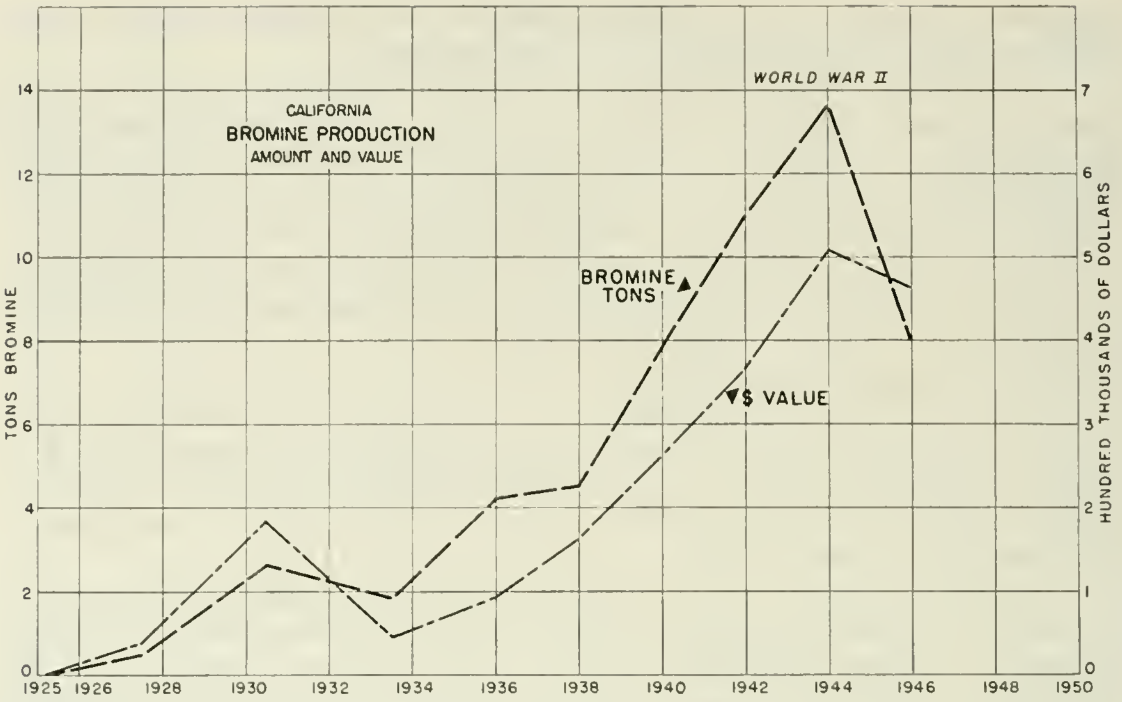

FIGURE 2. Chart showing amount and value of bromine produced in California, 1925-46. Curves based on 2- and 3-year averages.

corrosive. Bromine is not found uncombined in nature. The saline minerals carnallite and sylvite contain bromine as an impurity. Sea water contains from 0.0065 to 0.0070 percent bromine, which becomes concentrated in natural and artificial bitterns. Bromine associated with salines is thought to be in the form of magnesium bromide. The silver ore minerals bromyrite (AgBr), embolite [$\mathrm{Ag(Br,Cl)}$], and iodobromite ($\mathrm{2Ag,Cl \cdot 2AgBr \cdot AgI}$) contain bromide but are not commercial sources.

Uses and Prices. Ninety percent of the bromine produced is used in making ethylene dibromide for antiknock gasoline. Minor amounts are used for photographic emulsions and laboratory reagents.

Prices have remained constant during 1947 and 1948, according to the Oil, Paint, and Drug Reporter. The price of purified bromine is 19 to 28 cents a pound, ammonium bromide 36 to 37 cents a pound, sodium bromide and potassium bromide 33 to 34 cents a pound.

Preparation. The Westvaco Chlorine Products Corporation at Newark[33] recovers bromine, magnesium salts, and other compounds from bittern obtained from the neighboring plant of the Leslie Salt Company. The bittern at a density of 28° Baumé contains 0.121 percent bromine. The removal of bromine by a modified Kubierschky process is the first step in the treatment of the bittern.

Bittern, which is received only during the summer months, is stored in ponds of 200,000,000 gallons capacity. Raw bittern is neutralized with concentrated sulfuric acid and run into concrete storage tanks which hold several days' supply.

The bromine towers, of which there are three, are square hollow columns built of stone and loosely packed with ceramic ware. Bittern, which has been preheated, is fed in at the top, steam at the bottom, and

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[33] Seaton, M. Y., Bromine and magnesium compounds drawn from western bays and hills: Chem. Met. Eng., vol. 38, no. 11, pp. 638-640, November 1931.

chlorine gas at an intermediate point. Bromine is liberated according to the reaction:

$$MgBr_2 + Cl_2 \rightarrow MgCl_2 + Br_2$$

Ninety-five percent of the bromine is recovered. Hot bromine-free liquor is drawn from the base of the tower, while from the top comes a vapor containing bromine, a little chlorine, and water. This vapor goes to a stoneware condenser where the water and crude bromine are separated by gravity. The crude bromine is purified by distillation.

The American Potash and Chemical Corporation at Searles Lake obtains bromine by a similar process.[34] Bromine, which forms 0.085 percent of the raw brine, is made to crystallize isomorphously with the potassium chloride obtained from the main evaporator. A saturated solution of the mixed salts, which contains 1.8 percent bromine, is neutral and requires no acidification before treatment in Kubierschky towers. The liberated bromine vapor passes through tantalum-lined condensers and is purified to give bromine 99.9 percent pure.

Bromine products are liquid bromine, sodium bromide, potassium bromide, and ammonium bromide. Potassium chloride of chemical grade is made from the bromine-free effluent.

History of Operations. Production of bromine in California began in 1926 at Chula Vista, San Diego County, when the California Chemical Corporation built a Kubierschky tower for the recovery of bromine from salt-works bittern. A second bromine tower, built the same year at San Mateo, operated until late 1929 or early 1930. The Newark plant was built in 1931. In 1937, the California Chemical Corporation was acquired by the Westvaco Chlorine Products Corporation. Since 1945 no bromine has been produced at Chula Vista. Production of bromine at Searles Lake began in 1940.

CALCIUM CHLORIDE

In 1948 California produced 10,009 tons of calcium chloride, worth $167,610. This amounted to about 2 percent of the total United States consumption. The present California production is from Bristol Lake, San Bernardino County. Calcium chloride is a by-product of several chemical industries, but it has been estimated that only about 10 percent of the available supply is recovered in these operations. A little more than half of the United States supply comes from salt-refining operations, particularly in connection with the recovery of bromine and magnesia from Michigan and West Virginia brines; the remainder is produced by ammonia-soda plants.

Properties. Calcium chloride is a white soluble salt which is very hygroscopic. In addition to anhydrous calcium chloride, there are five hydrates. Of these, hexahydrated calcium chloride ($CaCl_2 \cdot 6H_2O$) is stable below 29° C. (85° F.). The water of crystallization is completely driven off by heating to 200° C. The anhydrous salt can absorb more than its weight of water in 24 hours, and even $CaCl_2 \cdot 6H_2O$ is hygroscopic.

Forms of Commerce. Fused or anhydrous calcium chloride is available in C.P., U.S.P., and technical grades. Partly dehydrated calcium chloride is sold in solid form containing 73 to 75 percent $CaCl_2$, and in

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[34] Armstrong, E. F., and Miall, L. M., Raw materials from the sea, p. 86, Brooklyn, Chemical Publishing Co., 1946.

FIGURE 3. Chart showing amount and value of calcium chloride produced in California, 1920-48. Two-year averages used for 1923-45.

flake or powder form containing 77 to 80 percent $CaCl_2$. Solutions containing 40 percent $CaCl_2$ are sold in tank-car lots.[35] Much of the calcium chloride produced from salt-works bittern contains from 2 to 6 percent magnesium.

Occurrence. Chlorocalcite or hydrophilite, the natural calcium chloride, is a mineralogic curiosity, but calcium chloride is present in the complex saline mineral tachhydrite ($CaCl_2 \cdot 2MgCl_2 \cdot 12H_2O$) and as an impurity in carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$). Most brines contain calcium chloride. In minute quantities it is present in most river and spring water. Brine in the Ventura County oil fields contains an unusually high proportion of calcium chloride.[36]

Production at Bristol Lake, San Bernardino County, comes from the calcium chloride-rich brine which fills the interstices of the crystal body. Calcium chloride is shipped in both liquid and flake form,[37] but no details are available. Four companies operated at Bristol Lake in 1947. Production has come in the past from salt-works bittern at Niland, Imperial County, and Chula Vista, San Diego County.

Uses. Most of the uses of calcium chloride depend on its deliquescence or on the low freezing point of its solution. It is used as a drying

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[35] Tyler, P. M., Calcium chloride: U. S. Bur. Mines Inf. Circ. 6781, pp. 1, 2, 1934.

[36] Hudson, F. S., and Taliaferro, N. L., Calcium chloride waters from certain oil fields in Ventura County, California: Am. Assoc. Petroleum Geologists Bull., vol. 9, no. 7, pp. 1071-1088, 1925.

[37] Dolbear, S. H., Economic mineral resources and production of California: California Div. Mines Bull. 130, p. 90, 1945.

agent not only in the laboratory but on an industrial scale. Spread on secondary roads, it prevents dust and aids stabilization by keeping the road damp. It is also used for controlling dust in coal and coke. For refrigeration brine and for control of ice on roads and railways, calcium chloride is preferred because it is relatively non-corrosive. It is used as an antifreeze in fire barrels, but is not satisfactory for use in automobile radiators.

The addition of calcium chloride to portland-cement concrete accelerates the time of setting, increases both the early and final strength, aids curing, and increases workability. These effects are accentuated in cold weather. One to four pounds of calcium chloride per bag of cement may be used, the higher amount being recommended for temperatures below freezing.

The following data show the increase in compressive strength of concrete resulting from the addition of 2 percent (about 1.9 pounds per bag) of calcium chloride. Tests were made by the Portland Cement Association.

Age of test	*Percent increase*
2 days	48
7 days	25
28 days	7
90 days	7
1 year	12
3 years	9

Smaller amounts are used for fireproofing paints, sizing compounds, wood preserving, and chemicals.

Prices. California producers value their product at about $5.00 a ton at the plant. Prices for packaged calcium chloride are much higher.

The Oil, Paint, and Drug Reporter quoted the following prices for 1948:

Flake, 77-80 percent, in paper bags, $21.50 per ton at the works.
Solid, 73-75 percent, in drums, $21.00 per ton at the works.
Liquor, 40 percent, in tank cars, $8.50 per ton at the works.

GYPSUM

The 1948 production of gypsum in California was 962,038 short tons valued at $2,354,390, an all-time high. This amounted to about 1 percent of the value of the 1948 California mineral production, exclusive of oil and gas. Rock gypsum is mined in the Little Maria Mountains, Riverside County; the Fish Creek Mountains, Imperial County; and near Cuyama Wash, Ventura County. Large tonnages of gypsite are mined in the southwestern part of the San Joaquin Valley. Not included in the production figures is the artificial gypsum produced from salt-works bittern as a by-product of magnesia manufacture.[38]

Although there are large undeveloped gypsum deposits in California, large quantities of raw gypsum and finished gypsum products, aided by favorable transportation costs, are brought into the state. Raw gypsum comes by ship from San Marcos Island in the Gulf of California; raw gypsum and gypsum products come by rail from Nevada.

Mineralogy and Geology. Most commercial gypsum ($CaSO_4 \cdot 2H_2O$) is a massive, impure material known as rock gypsum. Gypsite, which consists of gypsum mixed with sand or clay in earthy, efflorescent deposits,

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[38] See the section on Magnesite, Magnesium, and Magnesium Compounds in this bulletin.

is also important commercially. Other less-common varieties are the platy type known as selenite, the fibrous type known as satin spar, and the massive white, sometimes translucent type known as alabaster. Gypsum is commonly associated with anhydrite ($CaSO_4$), a mineral of little commercial value.

Several additional calcium sulfate substances can be prepared in the laboratory by calcining gypsum under controlled conditions. These include two forms of the hemihydrate ($CaSO_4 \cdot \frac{1}{2}H_2O$), and two forms of soluble anhydrite which may contain as much as 1 percent H_2O.[39] These dehydration products may easily be rehydrated. All four sometimes form in the commercial calcining kettle and are therefore of more than theoretical interest.

Most natural calcium sulfate minerals have formed through the evaporation of sea or saline lake waters, but some also occur in hydrothermal veins, in near-surface veins formed by deposition from groundwater, and as replacements of limestone. In saline deposits at least part of the calcium sulfate is believed to have originally precipitated as anhydrite and to have been altered to gypsum by the action of ground water.

The largest deposit now worked in California is of Tertiary age, but some of the older mines that still produce important tonnages are in pre-Tertiary rocks. There are also large reserves of pre-Tertiary gypsum that have been but little developed. Recent deposits of gypsite are an important source of agricultural gypsum. Thirty years ago a playa deposit of Quaternary age was the largest single source of gypsum, but it is no longer worked.

Localities. Gypsite is mined along the southwest margin of the San Joaquin Valley from Little Panoche Creek to Maricopa, and additional tonnages are obtained from the margins of old Kern Lake and the playa at Saltdale, Kern County. In the past it has been mined also near Carrizo Plain, San Luis Obispo County; Palmdale, Los Angeles County; along Cottonwood Creek, Kern County; and near Corona, Riverside County.

Gypsite consists of an unconsolidated, earthy mixture of very finely divided gypsum and clay or silt. Samples may contain 80 percent or more gypsum, but because the deposits are irregular, few miners can consistently produce gypsite containing more than 70 percent gypsum. Some gypsite contains only 50 percent gypsum. Most deposits are at or within a few inches of the surface. Deposits as thin as 6 inches have been worked, and few exceed 6 feet in thickness. Most operators mine with carryall scrapers. This cheap method of mining, together with the proximity of the deposits to the San Joaquin Valley farms, make the mining of these low-grade gypsum deposits profitable.

Gypsite forms only in regions of little rain and fast evaporation. Calcium sulfate bearing ground water is drawn upward by capillary action, and small gypsum crystals form at or close to the surface. On the west side of the San Joaquin Valley most of the Tertiary formations contain gypsum along fractures or as part of the cement of sandstones.

Gypsite which has formed on the outcrops of gypsiferous rocks is called "cap gypsum" by the miners at McKittrick. Probably most of the deposits are of this type. Gypsite is derived from the McKittrick formation at McKittrick and Carrizo Plain; the Paso Robles formation at

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[39] Kelley, K. K., Southard, J. C., and Anderson, C. T., Thermodynamic properties of gypsum and its dehydration products: U. S. Bur. Mines Tech. Paper 625, pp. 3-9, 1941.

VIEW NORTH TOWARD WHITEROCK BLUFF

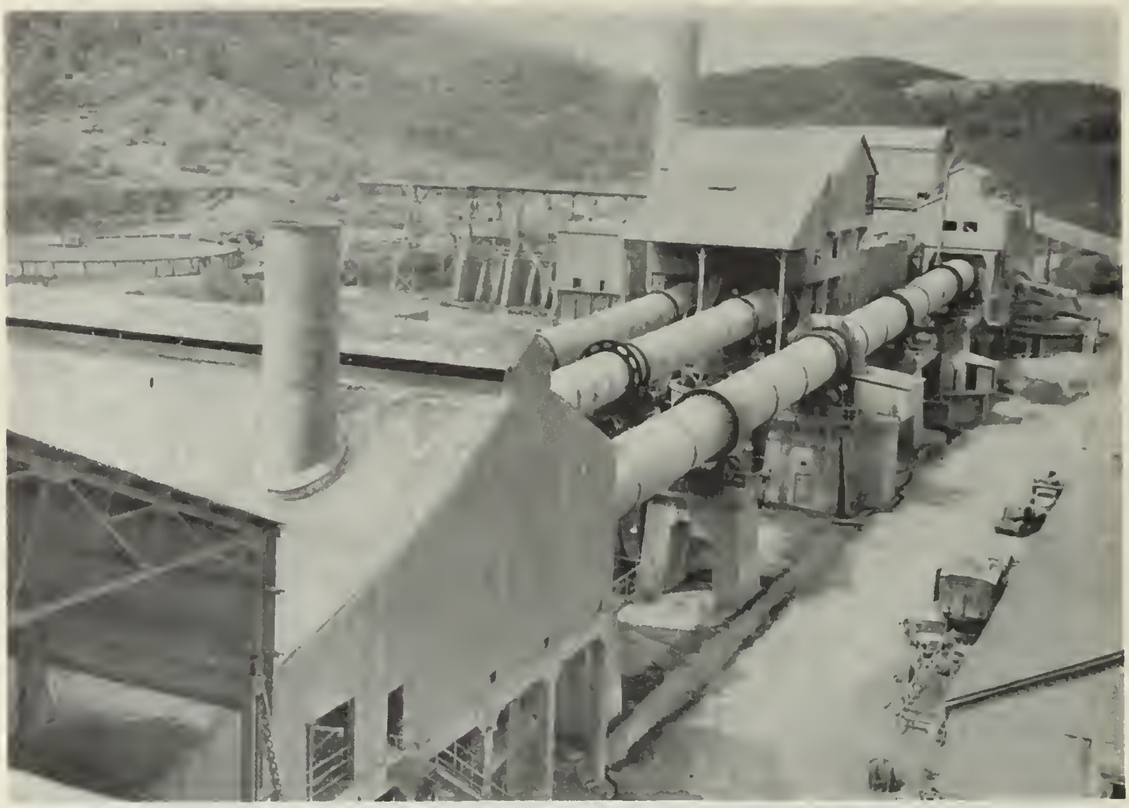
From south bank Cuyama River. Shows early development in Whiterock area of Russell Ranch oil field.
Ira Carroll, photography, 1948; courtesy Richfield Oil Corporation.

AERIAL VIEW NORTH TOWARD NATIVIDAD DOLOMITE QUARRY AND CALCINING PLANT OF KAISER ALUMINUM AND CHEMICAL CORPORATION

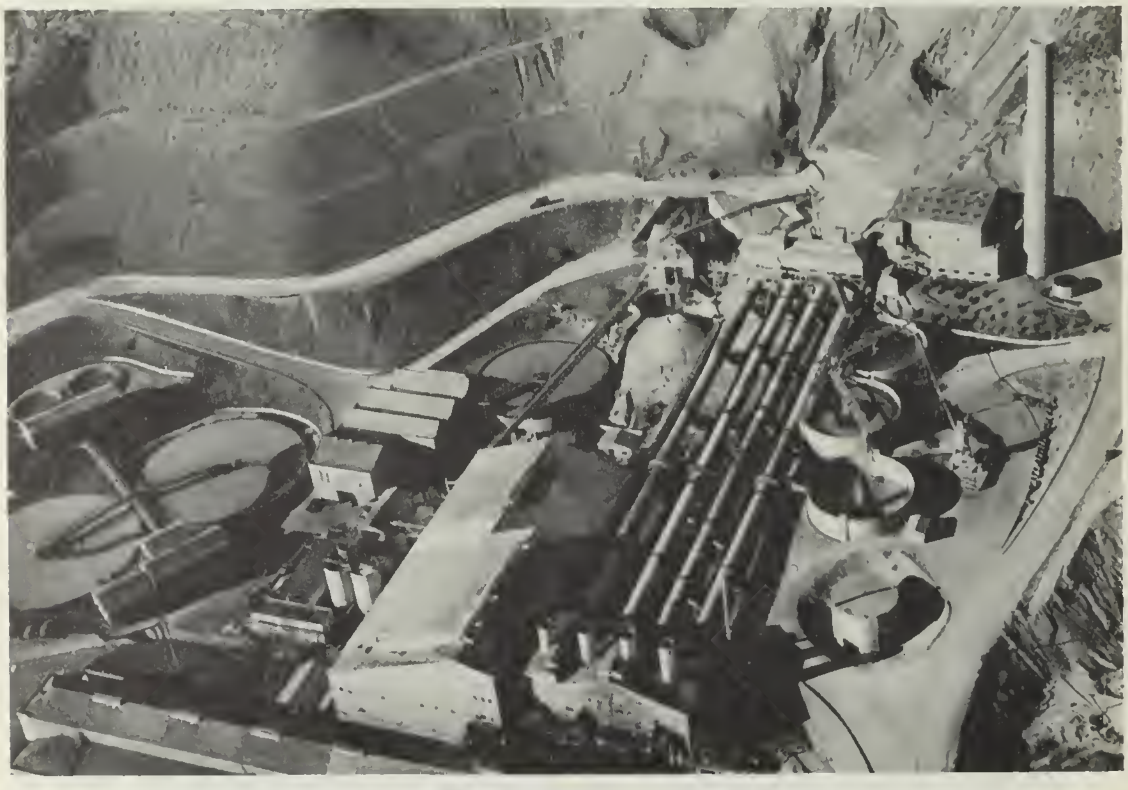
Near Salinas, Monterey County. Dolomite from quarry, right, is processed in plant at left. Dolomite is from early Paleozoic or pre-Cambrian Sur series. *Moulin Studios, photography, 1948; courtesy Kaiser Aluminum and Chemical Corporation.*

AERIAL VIEW OF SEA-WATER CHEMICAL PLANT AND REFRACTORY BRICK PLANT OF KAISER ALUMINUM AND CHEMICAL CORPORATION

Moss Landing, Monterey Bay, Monterey County. Magnesium hydroxide, which is precipitated from sea water by the addition of calcined dolomite, is settled in the large tanks in the foreground. The principal product of the plant is magnesia (magnesium oxide), which is used as a refractory. The adjacent refractory brick plant is at right center. *Photography, 1949; courtesy Kaiser Aluminum and Chemical Corporation.*



A, CALAVERAS CEMENT COMPANY PLANT
San Andreas, Calaveras County. The long kiln at right was installed in 1946. Limestone used in this plant is obtained from Carboniferous Calaveras formation. *Haas and Associates, photography, 1948; courtesy Calaveras Cement Company.*



B, PERMANENTE CEMENT COMPANY PLANT
Permanente, Santa Clara County. This is the largest cement plant in the west; annual capacity is 5,500,000 barrels. Limestone and clay, quarried near the plant, are stock piled on slope to left of stack. Limestone quarry is in Jurassic (?) Calera limestone. Kilns are 463 feet long. *Photography, 1948; courtesy Permanente Cement Company.*

A, PLANT OF U. S. LIME PRODUCTS CORPORATION
Sonora, Tuolumne County. Limestone used here is from Carboniferous Calaveras formation. *Olaf P. Jenkins, photography, 1948.*

B, FOUCH-THOMPSON PUMICE PIT
Siskiyou County. Loading pumice for use as light-weight aggregate in building blocks. *Charles W. Chesterman, photography, 1948.*

AERIAL VIEW EAST TOWARD CLAY PITS AT LINCOLN, PLACER COUNTY

Gladding, McBean & Company's mine and mill in foreground and center left. Pit and plant of Lincoln Clay Products Company in center right. Gladding McBean Towle pit is the quarry in the background. *United Aerial Survey, Tulare, California, photography, 1948.*

KAISER STEEL CORPORATION'S BLAST FURNACES

At Fontana, 50 miles east of Los Angeles, in San Bernardino County. Furnace at right began production in October 1949; the original unit, at left, has been producing since 1943. Iron ore for furnaces is obtained from the company's Eagle Mountain mine in San Bernardino County. *Photography, 1949; courtesy Kaiser Steel Corporation.*

AERIAL VIEW, ROUTE OF PACIFIC GAS AND ELECTRIC COMPANY'S 34-INCH NATURAL GAS TRANSMISSION MAIN

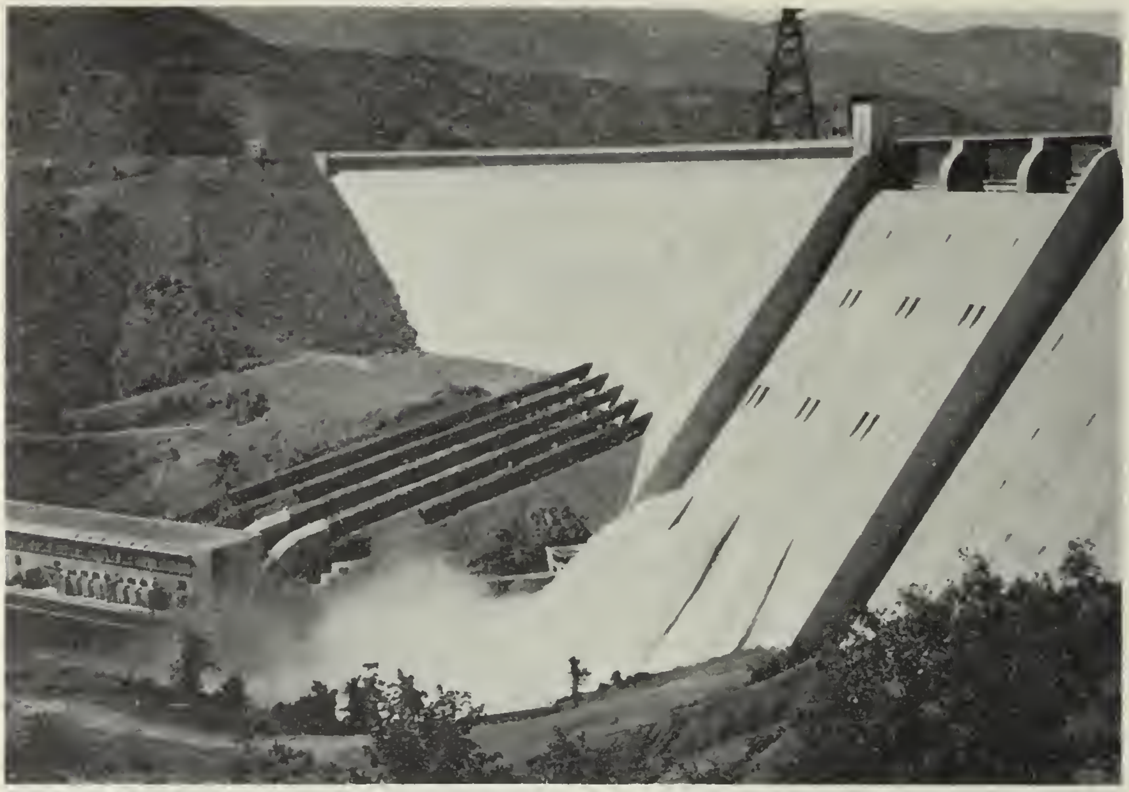
From California-Arizona border at Topock on the Colorado River west into Mojave Mountains. The 506-mile "Super Inch" from Topock to Milpitas is being built to deliver Texas and New Mexico natural gas to northern California, beginning January 1, 1951. Delivery from the transmission system of El Paso Natural Gas Company will be taken at midstream on the bridge at left foreground, an abandoned highway bridge bought to support the pipe at the river crossing. *Photography, 1949; courtesy Pacific Gas and Electric Company.*

A, MALAKOFF HYDRAULIC PIT AT NORTH BLOOMFIELD, NEVADA COUNTY

Gold was produced from gravel mined on a large scale from a Tertiary river channel until 1884, when an injunction obtained in Federal Court by agricultural interests practically put a stop to hydraulic mining. *Photography, 1949; courtesy Thomas F. Ryder.*

B, HYDRAULIC MINING AT RELIEF HILL, NEVADA COUNTY

This is one of the few hydraulic mines to produce gold on a considerable scale in recent years. Such mines by Federal law must operate behind debris dams to restrain the tailing in the drainage basins of the Sacramento and San Joaquin Rivers. *Photography, 1949; courtesy Thomas F. Ryder.*



A, SHASTA DAM, SHASTA COUNTY
Olaf P. Jenkins, photography, 1946

B, LARGE OBSIDIAN FRAGMENTS
Quarried from broken pumiceous obsidian. Clear Lake Park, east side of Clear Lake, Lake County. *Olaf P. Jenkins, photography, 1949.*

A. KYANITE QUARRY NEAR OGILBY, IMPERIAL COUNTY

This deposit, which was worked from 1925-46, has been the principal source of kyanite in the western United States. The kyanite occurs in quartzose parts of a pre-Mesozoic metasedimentary formation. *Lauren A. Wright, photography, 1949.*

B, CENTRAL PART OF WESTERN TALC DEPOSIT, NORTHERN SAN BERNARDINO COUNTY

Talc body lies at contact between diabase sill and late pre-Cambrian siliceous dolomite. This deposit, which has been in almost continuous operation since 1917, has yielded nearly 200,000 tons of talc. *Lauren A. Wright, photography, 1949.*

AERIAL VIEW EAST TOWARD STACKING GROUND AND REFINERY, LESLIE SALT COMPANY, NEWARK, ALAMEDA COUNTY

Salt is obtained from sea water by solar evaporation in ponds covering 40,000 acres along southern end of San Francisco Bay. *Photography, 1948; courtesy Leslie Salt Company.*

MILL OF THE MOUNTAIN COPPER COMPANY, LTD., SHASTA COUNTY
Here pyrite from the Hornet mine is prepared for shipment to acid plants on San Francisco Bay.
Photography, 1948; courtesy The Mountain Copper Co., Ltd.

A, WESTERN REFRACTORIES COMPANY'S YOSEMITE PIT NEAR CARBONDALE, AMADOR COUNTY

Mining fire clay from Ione formation for manufacture of fire brick in the company plant at Ione. *Mort D. Turner, photography, 1949.*

B, DESERT MATERIALS CORPORATION PUMICE PIT

Coso Range, Inyo County. Pumice is used as light-weight aggregate in building blocks and acoustical plaster. *Charles W. Chesterman, photography, 1948*

A, PACIFIC COAST AGGREGATES, INC., CENTERVILLE, ALAMEDA COUNTY
Mining gravel with dragline for concrete-aggregate. *Fenelon F. Davis, photography, 1949.*

B, VIEW WEST TOWARD ROCKAWAY QUARRY
Rockaway Beach, San Mateo County. Quarry is in Jurassic (?) Calera limestone, which is used for road construction. *Fenelon F. Davis, photography, 1949.*

A, J. M. NELSON BASALT QUARRY, SOLANO COUNTY
Basalt is quarried from Sonoma formation for use as crushed rock and road metal.
Charles W. Chesterman, photography, 1949.

B, THOMPSON DIVIDE MINING COMPANY
Mining gold by dragline dredge on Trinity River above Lewiston, Trinity County.
John C. O'Brien, photography, 1947.

Kettleman Hills; the Tejon formation near Coalinga; the Vaqueros formation at Tumey Gulch; and the Etchegoin and Jacalitos formations in the Panoche Hills. Gypsite at Palmdale, Los Angeles County, rests on a gypsiferous shale member of the Escondido formation.

"Cap gypsum" deposits closely follow the present surface, although the overburden is thin or lacking on the upper parts of hillsides, and thicker toward the base. The bottom contact of some deposits is sharp, but the gypsite ordinarily grades into the underlying material. Examples include some of the McKittrick Agricultural Gypsum Company's deposits at McKittrick, the idle Carissa mine at Carrizo Plain, the Griffin mine at Tumey Gulch, and the Valley View mine in the Panoche Hills.

Important gypsite deposits are found along the margins of periodic lakes. Efflorescent deposits, derived from the underlying soil, form along the shore line, although the lake water itself may never have been saturated with gypsum.[40] Gypsite bodies thus formed are irregular lenses that lie with a sharp contact on lake beds. Solution cavities are a characteristic feature. The Pacific Gypsum Company's deposit on the south margin of old Kern Lake, the Daly deposit near Saltdale, and probably H. M. Holloway's Avenal Gap mine belong to this class.

The Lost Hills deposits of H. M. Holloway Inc., one of the largest producers of gypsite, have some of the features of the lake type. The surface formation is a slightly consolidated silty sand which contains conglomerate lenses. Gypsite bodies as much as 20 feet thick occur within 3 to 10 feet of the surface. Many of the bodies are elongate and some follow existing gullies. In many places gypsite lies on clay, but in some places there is coarse sand between the gypsite and the clay. Lenses of sand have been found within the gypsite bodies.

A third type of gypsite deposit which is found at McKittrick has been called "channel gypsum" by the miners there. Southwest of McKittrick two such deposits have been worked. They are long, narrow deposits that closely follow present dry washes and seem to have formed in the stream beds by the evaporation of gypsiferous ground water. The gypsite lies beneath as much as 5 feet of slightly consolidated sand and gravel containing shale fragments. Toward the base the gypsite grades into gypsiferous sand and clay, and in places it lies on creek gravel containing gypsum fragments as much as an inch long.

The crystal body of Bristol Lake, San Bernardino County, consists largely of gypsum, and prior to 1924 a large plaster mill at Amboy was supplied from it. Gypsum lies beneath a foot or two of salty sand and extends to an unknown depth below the water level, a distance of 6 to 8 feet below the surface. The character of the gypsum varies from clean white granular gypsum to salty dirt containing gypsum crystals. Gypsum crystals are sometimes an inch or more in maximum dimension. This gypsum had to be washed free of salt and dirt before use. A similar deposit is said to exist in the neighboring Danby Lake, but no details are available.

Rock gypsum deposits of Tertiary age include the United States Gypsum Company's mine in the Fish Creek Mountains, Imperial County, the largest gypsum mine in the state. This deposit, which is at the north end of the Fish Creek Mountains, is part of a formerly much more exten-

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[40] Hess, F. L., A reconnaissance of the gypsum deposits of California: U. S. Geol. Survey Bull. 413, pp. 23-25, 1910.

sive deposit that has been dissected by erosion. In the mine area the gypsum beds have been preserved in a shallow synclinal basin 3 miles long and half a mile wide. The beds, except for violent local contortions in the gypsum, dip uniformly at angles of from 25° to 35° toward the synclinal axis.

The gypsum is included in Miocene beds that have been differentiated by Dibblee.[41] They lie on a pre-Cretaceous basement of metamorphic rocks intruded by coarse gneissic granite. The gypsum is underlain by the Split Mountain formation which in its lower part consists of coarse, arkosic, red-weathering sandstone with conglomerate beds composed of cobbles of all the older rocks. The upper part is a gray boulder conglomerate with subordinate layers of gray arkosic sand. In most places such sand immediately underlies the gypsum. Overlying the gypsum is the Imperial formation containing clay beds alternating with limonite-cemented quartz sand. These beds have been largely removed by erosion. Eastward the underlying Split Mountain formation pinches out and is overlapped by the gypsum.

Other large but inaccessible remnants of the original deposit are known to exist to the south, and there may be extensions westward into San Diego County.

Another Tertiary deposit is that of the Monolith Portland Cement Company in Quatal Canyon near Cuyama Wash, Ventura County. This deposit consists of a single bed of massive brown gypsum 10 to 30 feet thick that may be traced for at least seven miles. The gypsum is contained in a brown clay, and the clay in turn is contained in a great thickness of coarse, slightly indurated sandstone. The Blue Diamond Company owns patented claims adjoining the Monolith Portland Cement Company's property on the northwest.

A second gypsiferous horizon in the Cuyama Wash region lies about five miles southwest of the Quatal Canyon deposit. It consists of thin beds and impure beds of gypsum from which gypsite deposits have been derived. Masses of alabaster up to a maximum of ten feet in largest dimension occur in it also. Exploratory work has been done in numerous places, but only a small tonnage of gypsum has been shipped. The terrestial clays that contain both groups of gypsum deposits grade into marine sediments northwestward along the strike; to the southeast the clays become coarse.[42]

In the northern foothills of the Avawatz Mountains, San Bernardino County, gypsum, together with salt and celestite, occurs in lake beds involved in the complicated structures along the Garlock and related faults. Gypsum and interbedded gypsiferous clay occur in two roughly parallel zones as much as 400 feet thick and 9 miles long. Celestite is interbedded with the gypsum in the western part of the deposit, but the salt is in fault contact with the gypsum bodies. The lake beds consist mostly of bright yellow, gray, and red clays. Although there has been much development work, there has been no production.

A deposit at China Ranch, San Bernardino County, was mined from 1914-18. Here a great thickness of brown clay shale contains gypsum beds totaling 20 feet in thickness. Individual beds from 6 inches to 3 feet thick are separated by as much as 3 inches of shale. The gypsum is white and of medium grain size. The beds dip as much as 25°.

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[41] Dibblee, T. W., Jr., Geology of the Split Mountain area: unpublished, 1944.
[42] Dibblee, T. W., Jr., personal communication.

Similar but smaller Tertiary deposits are found at Owl Hole, Copper Canyon, and Furnace Creek in the Death Valley area. Other Tertiary deposits, some of which have been worked, are near Point Sal, Santa Barbara County; Fillmore, Ventura County; in Mint Canyon, Los Angeles County; and on the Tannehill Ranch, San Benito County.

Pre-Tertiary deposits of gypsum occur in the Little Maria Mountains, Riverside County, where the Midland operations of the United States Gypsum Company and the American Gypsum Company's mine are located. The gypsum beds form part of a series of slightly metamorphosed sediments that cross the range from east to west. The sediments are bordered on the north by granitic rocks and on the south by gneiss. The rocks of the gypsum belt are quartzite, crystalline limestone, and quartz-albite-mica schist, which dip 50°-80° NW. Gypsum occurs in the limestone as persistent beds up to 50 feet thick and in the schist as lenticular bodies which have a more limited extent along the strike. The gypsum is a coarse-grained snow-white aggregate of transparent grains. In many places it contains thin layers and lenses of schist, and schist is present also in gypsum interbedded with limestone. Anhydrite, is present at depth, and is the mineral from which the gypsum has formed. In the United States Gypsum Company's underground workings there is evidence that the extent of the alteration of anhydrite to gypsum depends on the presence of fractures and other openings that allowed the access of water.[43]

Similar but undeveloped deposits have been found in the Maria Mountains, the Palen Mountains,[44] and the Riverside Mountains, Riverside County.

Uses. Most of the gypsum used in California is consumed in agriculture and by the plaster industry. The portland-cement industry probably consumes about 10 or 15 percent of the output.

The most important function of gypsum in agriculture is the conditioning of alkali soils. By control of the ratio of calcium ions to sodium and potassium ions, the clay particles are prevented from deflocculating, and become very hard when dry. Gypsum also changes the harmful black alkali (sodium carbonate) to the relatively harmless white alkali (sodium sulfate). Gypsum is a source of both sulfur and calcium and is particularly useful in soils which are not acid. Rock gypsum to be used for agriculture is finely ground, but gypsite requires no preparation.

A little less than half the gypsum consumed in California is calcined and made into gypsum board, lath, and plaster. Five calcining plants are now operating, but only two are processing crude gypsum mined in the state. Two of the remaining three plants own and operate mines outside the state, and the third purchases gypsum from out-of-state sources.

Calcining must be done under carefully controlled temperatures which range from 250° to 350° F. Overcalcining produces dead-burned gypsum or anhydrite which will not rehydrate. Uncalcined lumps of gypsum act as a powerful accelerator and are highly objectionable.

Batch machines called kettles are used for all but the lower grades of stucco (calcined gypsum). The typical kettle in California plants is a

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[43] C. L. Conway, personal communication.

[44] Harder, E. C., The gypsum deposits of the Palen Mountains, Riverside County, California: U. S. Geol. Survey Bull. 430, pp. 407-416, 1910.

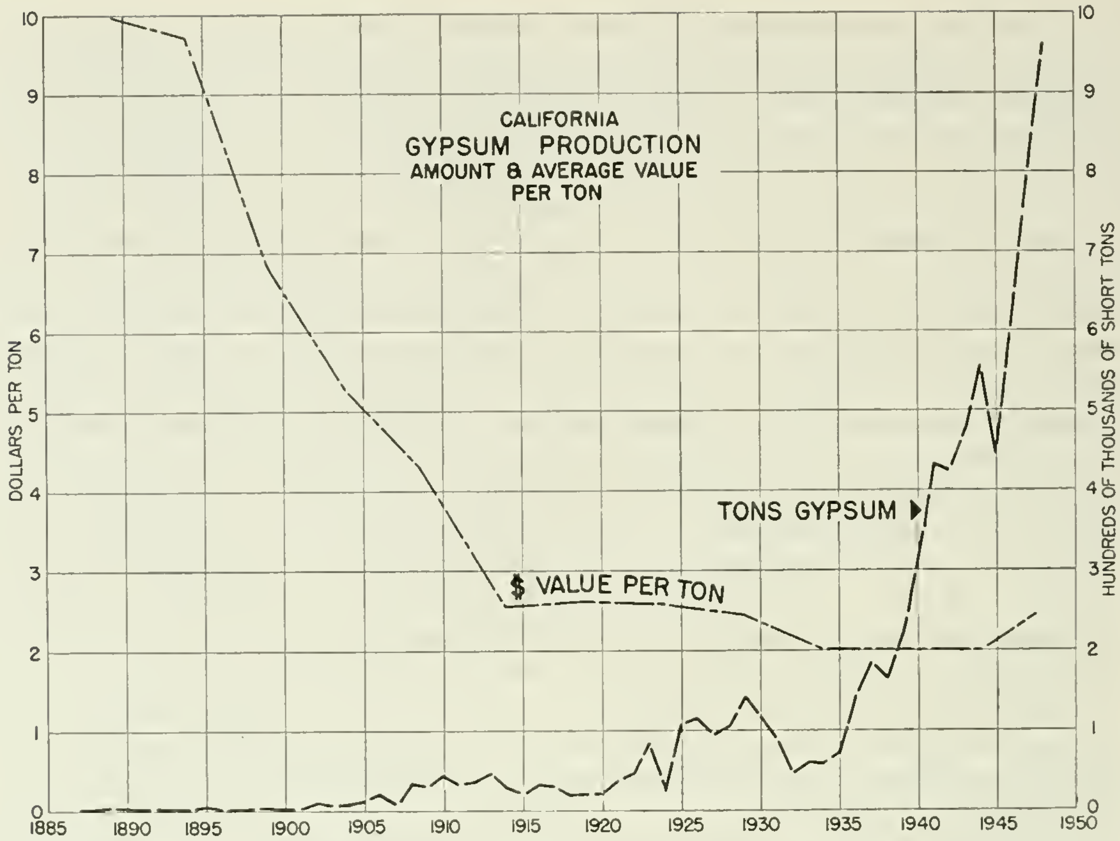

FIGURE 4. Chart showing amount and average value per ton of gypsum produced in California, 1887-1948. Value per ton curve based on 5-year averages.

brick-lined steel cylinder heated from below by an oil- or gas-fired furnace and also by four large horizontal flues through which the furnace gases pass. The boiling action caused by the water of hydration being driven off produces the necessary agitation, but additional action by rabble arms close to the bottom prevents sticking. A charge consists of 10 to 12 tons of gypsum ground to 80 percent minus 100 mesh. During calcining, which takes about $2\frac{1}{4}$ hours, the temperature is gradually raised from 250° to 350° F. The finished batch is dumped into a hot pit before removal to storage bins.

Stucco can be made by continuous methods, but at present it is not possible to produce a product sufficiently uniform for all purposes. Two of the California plants use the Raymond Imp mill which is essentially a hammer mill through which are passed the hot gases from an adjacent furnace. Gases enter the mill at 1700°F., and stucco is withdrawn at 350°F., 90 percent minus 100 mesh. It is then separated from furnace gases and steam, and put in storage bins.

Hardwall plaster is made from kettle stucco reground dry in tube mills. The ground stucco is then mixed with fiber, sometimes sand, and a retarder. For casting plaster, kettle stucco is reground in buhr mills.

Gypsum wall board and lath may be made from stucco produced by continuous methods. These products are made on Ehrsam machines which are almost entirely automatic.

The portland-cement industry uses raw gypsum as a retarder. About 10 pounds of gypsum consisting of at least 92 percent $CaSO_4 \cdot 2H_2O$ are added per barrel of cement. Probably most of the mills in California are accustomed to using, and therefore require, gypsum which is plus

⅜ inch and minus 1½ inch. Some, however, require finely ground gypsum, and a few are equipped to handle both pebble and finely ground gypsum.

Prices. The price of crude gypsum is about $2.60 a short ton for material suitable for cement retarder and plaster manufacture. The price of agricultural gypsum depends on the grade. Gypsite containing 60 percent gypsum sells for about $2 a ton at the mine. The Bureau of Labor Statistics has estimated that base-coat plaster sells for $13.74 per ton f.o.b. car's destination and that plaster lath sells for $18.26 per 1000 square feet.[45]

Mining. Gypsite is commonly mined with carryall scrapers. Deposits are prospected with bulldozer trenches, and little development is necessary other than the construction of truck-loading chutes. Much of the gypsite is loaded into the customer's truck for transport directly to the fields.

Rock gypsum must be drilled and blasted. The Fish Creek Mountain deposit has been developed by means of an open cut which in 1942 was 3000 feet long and 100 feet high.[46] At that time the practice was to break a large tonnage by blasting a series of churn-drill holes. Most smaller mines use wagon drills, and smaller, less regular benches are maintained. Steeply dipping deposits are mined by the open-stope method, or, more rarely, by shrinkage stoping.

History of Production. The outstanding feature of California's gypsum industry is the rapid increase in production in recent years. This growth in part reflects the increase in building activity. The application of gypsum to soils bearing certain crops has been greatly stimulated by the policy of the Federal Production and Marketing Administration, which makes payments to farmers for the application of agricultural gypsum on the basis of its contained sulfur content.

Although it has been stated that the earliest use for gypsum in California was for agriculture,[47] the Golden Gate Plaster Mill of Lucas and Company at San Francisco was in operation before 1875. It received at least part of its requirements from the Point Sal mine, Santa Barbara County.[48] In 1884 a mill at Los Angeles was grinding gypsum for agricultural use. At this time and earlier, crude gypsum was reported as being imported from Lower California, probably from the San Marcos Island deposit.

The Point Sal mine was closed in 1885 or soon after, but within the next 10 years other producers took its place. Among them were the Alpine Plaster Company and the Fire Pulp and Plaster Company at Palmdale, the Paoli mine near Mendota, the Coalinga mine, and Captain Fauntleroy's deposit on Cottonwood Creek. The Pacific Cement Plaster Company began operations at Amboy in 1904 and in succeeding years built the largest calcining plant in California of that time. This company was bought out by the United States Gypsum Company in 1919. In 1916 and 1917 the Acme Cement and Plaster Company operated a gypsum mine at China Ranch, San Bernardino County. Gypsum, which was produced from underground workings at the rate of 1000 tons a month, was shipped by rail to Los Angeles where it was calcined.

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[45] Harness, C. L., and Downey, M. G., Gypsum: Minerals Yearbook 1946, p. 594, 1948.

[46] Sampson, R. J., and Tucker, W. B., Mineral resources of Imperial County: California Div. Mines Rept. 38, p. 135, 1942.

[47] Santmyers, R. M., Development of the gypsum industry by states: U. S. Bur. Mines Inf. Circ. 6173, pp. 6-9, 1929.

[48] The minerals of California: California Min. Bur. Rept. 4, pp. 226-228, 1884.

The United States Gypsum Company's first interest in California came with the purchase of the Pacific Cement Plaster Company in 1919. It later acquired large holdings in the Little Maria Mountains and transferred its operations there in 1922-24. The Fish Creek Mountain deposit was first developed in 1920-22 and passed through several hands before the United States Gypsum Company bought it in 1945.

IODINE

California produces all the crude iodine recovered in the United States and provides about one third of the country's requirements.

Occurrence. Iodine, although a widely distributed element, occurs in small amounts and has not been found native (uncombined with other elements). Iodine-bearing minerals occur with certain silver and lead ores. The double salt, dietzeite [$Ca(IO_3)_2 \cdot CaCrO_4$], the calcium iodate, lautarite [$Ca(IO_3)_2$], and perhaps other iodates are iodine minerals found in Chilean caliche.[49] Iodine has been detected in plants and animals, particularly marine plants and animals, and apparently is essential for organisms.[50] Certain kinds of seaweed are a commercial source. Iodine occurs in artesian water in Java and Italy. Salt water produced with oil from oil wells, contains iodine in recoverable amounts. Most of the world's supply, however, has come from caliche deposits in Chile.

Localities. In California iodine is produced from the brines of certain oil wells in the Los Angeles area. In 1948 four plants were operated by the Dow Chemical Company and the Deepwater Chemical Company, one each at Dominguez Hill, Seal Beach, the Venice field, and the Inglewood field. Iodine is thought to be present as sodium iodide. The iodine content varies from well to well, and is less in the deeper zones. The brine is slightly alkaline and contains less salt than sea water. The iodine content varies from 10 to 100 parts per million.

*Analysis of brines from oil wells in the Los Angeles area.**

	Parts per million
SiO_2	34
Fe_2O_3 and Al_2O_3	55
Ca	520
Mg	234
Total alkali as Na	10,759
SO_4	40
Cl	15,100
HCO_3	1,584
I	50
Br	90
Total solids	28,301
Mineral solids	26,781
Volatile and organic materials	1,600

* Manning, P. D. V., Domestic iodine industry: Chem. Met. Eng., vol. 41, no. 11, pp. 568-570, Nov. 1934.

Utilization. Practically all the crude iodine used in the United States, although it is commonly over 99 percent pure, is refined or manufactured into iodine chemicals. The most important use is in medicine. Iodine is an essential element in food and is often added to salt and also

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[49] Holstein, P. F., Fortunes and misfortunes in iodine: Chem. Met. Eng., vol. 39, no. 8, p. 422, August 1932.

[50] Armstrong, E. F., and Miall, L. M., Raw materials from the sea, pp. 112, 113, Brooklyn, Chemical Publishing Co., Inc., 1946.

to the drinking water of some communities. Iodine and its compounds are important laboratory reagents and are also used in preparing photographic emulsions. The addition of potassium iodide to stock feed is becoming increasingly important; this practice is made feasible by the development of methods to prevent loss of iodine during storage.[51]

Crude iodine is used approximately as follows:[52]

Potassium iodide	70 percent
Sodium iodide	5 percent
Resublimed iodine	15 percent
All other compounds	10 percent

Markets. In 1948 California produced the only crude iodine recovered in the United States. Production for the years 1945 and 1946, the last years for which statistics are available, totaled 1,224,598 pounds, valued at $1,563,069. Imports of crude iodine in 1946 were 886,578 pounds, all of which came from Chile. California production, although amounting to only one-third of the United States consumption, has been a major factor in the control of the price of iodine.

According to the Oil, Paint, and Drug Reporter the price of crude iodine in 1948 was $1.729 a pound. During World War II the price was fixed by the Office of Price Administration at $1.28¼. With the removal of controls in November 1946, a gradual rise in the price began. There has been a similar rise in the price of resublimed iodine, which rose from $2.35 to $2.55 a pound during 1948. The price of potassium iodide was about $2.10 a pound.

Methods of Recovery. The method of recovery used by the Dow Chemical Company resembles the blowing-out process of the recovery of bromine. Oil-field waste water is received in tanks, where it is clarified. The water is acidified, and chlorine gas is added to liberate the iodine. Iodine is removed from the water in a blowing-out tower, which consists of a vertical cylinder packed with rings made of ceramic material. The water containing elemental iodine enters the top of the tower where it meets a rising current of air. Iodine is carried by the air out of the top of the tower to a similar but smaller tower, where it is absorbed by a solution of SO_2 in water according to the reaction: $I_2 + SO_2 + 2H_2O \rightarrow H_2SO_4 + 2HI$. The absorbing solution is maintained at a constant concentration of 1 pound of iodine per gallon by dilution with fresh water. Periodically some is drawn off and sent to the finishing department where the iodine is again liberated with chlorine. The concentration is now high enough to permit the recovery of the iodine by filtration. This product is purified by treatment with hot concentrated sulfuric acid and then dried. Operations at the Dow Company's Seal Beach plant are described in a recent article by Sawyer, Ohman, and Lusk.[52a]

The Deepwater Chemical Company treats cleaned brine from the oil wells with silver nitrate. A colloidal precipitate of silver iodide forms, which, with the aid of the coagulating agent ferric chloride, settles and remains in the precipitation tank after the clear liquid is decanted. The sludge, composed of silver iodide, ferric hydroxide, and ferric soaps, is heated with steam and treated with acid to remove iron. The silver iodide remaining is roasted and then placed in a tumbling machine with water

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[51] Tyler, P. M., and Coons, A. T., Iodine: Minerals Yearbook 1938, p. 1381, 1938.

[52] Tyler, P. M., Iodine, in Industrial minerals and rocks, Am. Inst. Min. Met. Eng., 1937.

[52a] Sawyer, F. G., Ohman, M. F., and Lusk, F. E., Iodine from oil well brines: Ind. and Eng. Chem., vol. 41, pp. 1547-1552, 1949.

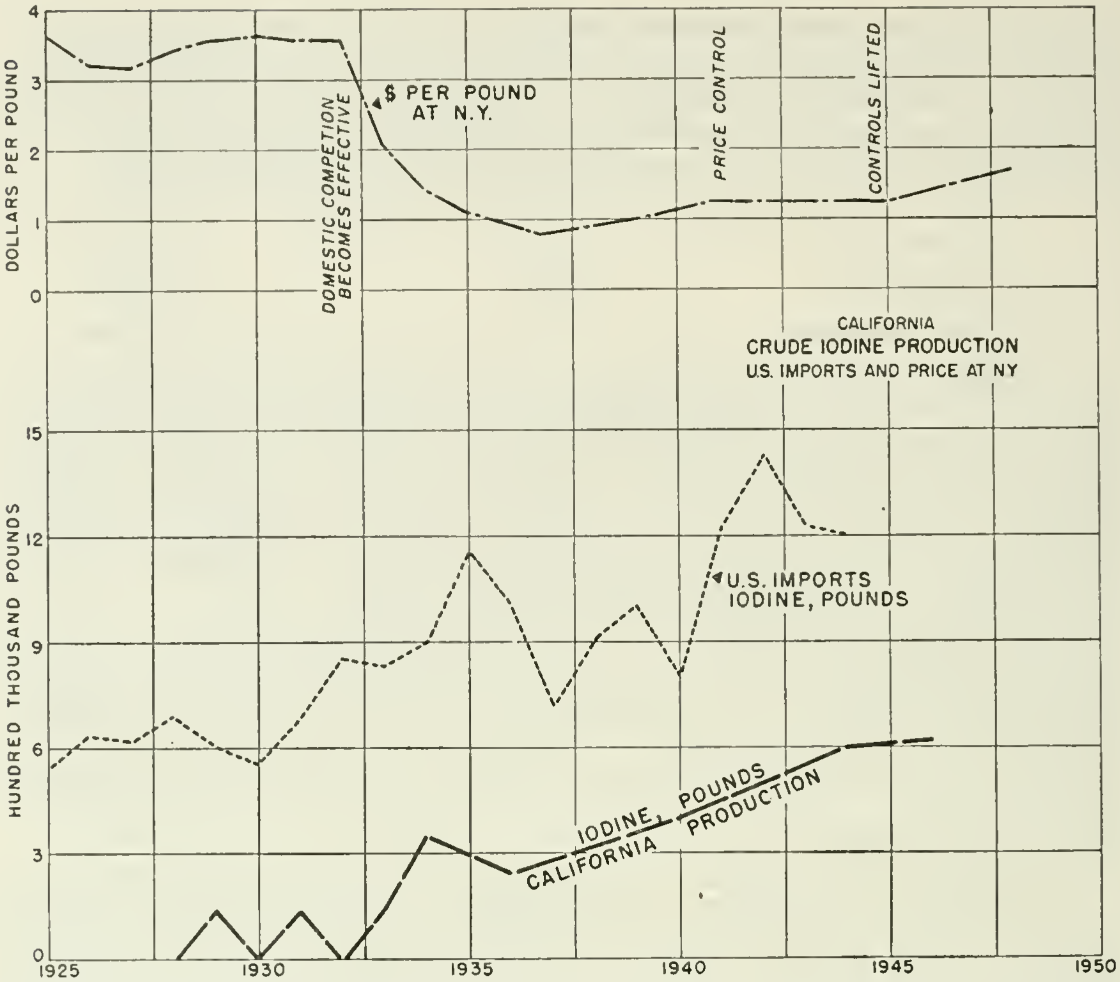

FIGURE 5. Chart showing crude iodine production in California, 1928-46; United States imports of crude iodine, 1925-44; and price per pound, 1925-48. Points on California production curve are 2- and 3-year averages. Points on United States imports curve represent a moving 5-year average.

and metallic iron. Silver is liberated and used again. Iodine is taken from the tumbling machine in the form of a concentrated solution of ferrous iodide. Chlorine is used to displace the iodine, which is filtered out of the solution.

History of Production. The iodine industry is comparatively young. It was not until 1811 that Bernard Courtois, a French manufacturer of saltpeter, discovered iodine while experimenting with seaweed ash remaining after the extraction of saltpeter.[53] In the early part of the nineteenth century iodine was produced together with saltpeter and other salts from seaweed in Scotland and France. Today there is still some production from seaweed in Europe, and also in Japan.

Today the most important source is the caliche of Chile, from which iodine is obtained as a by-product from the nitrate industry. The Chilean industry, established about 1874, soon acquired a world monopoly, and by 1946 produced about 75 percent of the world's requirements. Assuming normal production of nitrate, Chile could, by the most conservative estimate, produce the entire world's consumption of iodine.[54]

Prior to 1930 the price of crude iodine had been fixed for many years at about $4 a pound. Although using about 30 percent of the world's

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[53] Armstrong, E. F., and Miall, L. M., op. cit., p. 111.
[54] Holstein, P. F., op. cit., p. 424.

output, the United States produced very little iodine before this time. The only exception was a few pounds produced with other chemicals from seaweed by an experimental plant operated in southern California in 1917. In 1928 the Dow Chemical Company, which had been studying methods of recovering iodine from oil-field waste water, began producing iodine near Shreveport, Louisiana. Soon after, the General Salt Company began production at Long Beach, California, and was followed by the Deepwater Chemical Company. The Dow Chemical Company also built plants in southern California and abandoned the Shreveport operation in 1933. The General Salt Company ceased production in 1936. Two producers remained in operation.

American production, although not large, has had two effects. First is a marked reduction in the price of crude iodine. Crude iodine is imported duty free, yet the American industry has been able to establish itself. The second effect has been a program of research and education, the purpose of which is to increase the use of iodine. An increase has taken place which was in part stimulated by World War II.

Statistics. It is the policy of the Chilean Nitrate and Iodine Sales Corporation to maintain in New York a stock equal to about a year's supply. Yearly imports have always fluctuated widely and are not a reliable index of demand for iodine. In an effort to arrive at figures more representative a moving average over 5-year periods has been plotted. In California, in order not to reveal production figures of individual producers, productions for 2 or more years have been combined. The average value for these periods has been plotted.

LITHIUM

Since 1945 California has contributed nearly half of the lithia (Li_2O) produced in the United States. This production now comes entirely from Searles Lake where several hundred tons of a comparatively high-grade concentrate of dilithium sodium phosphate are recovered each year in connection with the soda and potash operation. Previous to 1927 the lithium-bearing mica lepidolite was obtained from pegmatites in San Diego County. Because of the high Li_2O content of the raw materials, the value of the present California production of lithium is greater than that of any other state. In tonnage, however, California is exceeded by South Dakota.

Properties. Lithium, one of the alkali metals, forms compounds which are in general similar to those of sodium and potassium. The chloride and the bromide of lithium are the most hygroscopic substances known. Lithium is the lightest of all metals (specific gravity 0.53), and even some of its alloys float on water.

Geologic Occurrence and Localities. At present the most important source of lithia in California is the brine of Searles Lake which contains between 0.02 and 0.03 percent lithium chloride by weight.

The operations of the American Potash and Chemical Corporation have already been discussed in this bulletin, and the lithia plant has been described by Gale.[55] In the evaporation process the concentration of lithium increases until the insoluble salt dilithium sodium phosphate (Li_2NaPO_4) forms. This is removed from the main evaporator with the sodium salts and recovered by flotation.

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[55] Gale, W. A., Lithium from Searles Lake: Chem. Industries, vol. 57, no. 33, pp. 442-446, Sept. 1945.

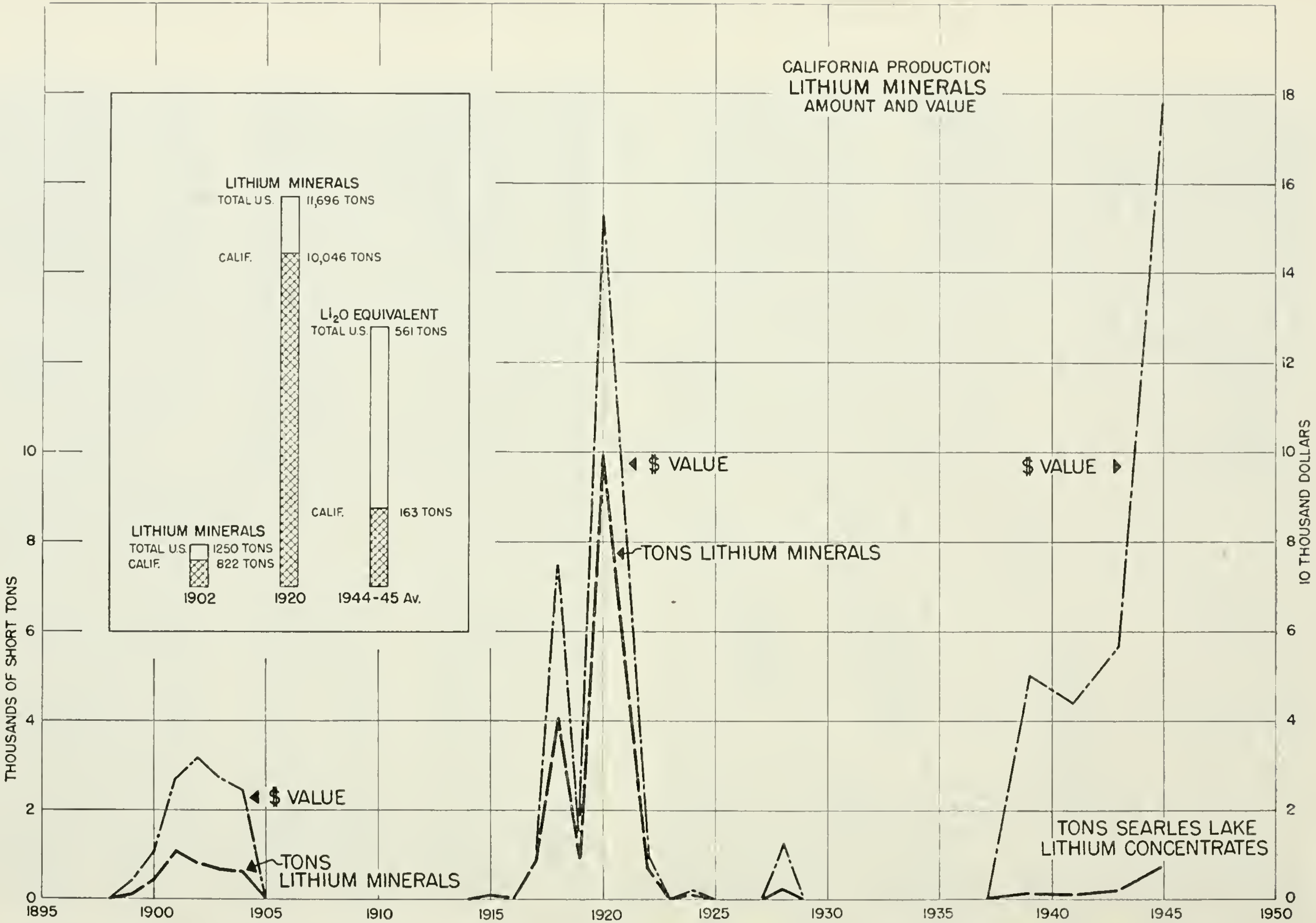

FIGURE 6. Chart showing amount and value of lithium minerals and lithium concentrates produced in California, 1898-1945.

Small amounts of lithium have been detected in mineral springs, sea water, and in plants.

Naturally occurring commercial lithium minerals, none of which contain more than 10.1 percent of lithia, are almost invariably confined to pegmatites. Usually the lithia content of these minerals is less than the theoretical maximum, largely because of replacement of lithium by sodium or potassium. Lepidolite, a pale pink or lilac potassium mica containing 2 to 4 percent lithia, has been the most important commercial lithium mineral in California. Amblygonite [$LiAl(F,OH)PO_4$] contains 8 to 9 percent lithia and has also been mined in California, but in much less quantity than lepidolite. Spodumene [$LiAl(SiO_3)_2$], which is now the world's most important source of lithium, is a prominent constituent of numerous lithium-bearing pegmatites in California; but it has been produced in very small quantities from these deposits.

Previous to the first commercial recovery of lithium from Searles Lake, lithium minerals had been obtained from a group of pegmatite dikes in the vicinity of Pala, San Diego County. Though lithium-bearing gem stones[56] have been produced from numerous mines in the area, a single property, the Stewart mine, has yielded most of the lithium for commercial purposes. The known commercial concentrations of lithium-bearing minerals at this deposit are confined to a bulge in an elongate pegmatite dike. The bulge, which is approximately 80 feet thick, contains a discontinuous quartz-spodumene core in its central portion. About the core several pegmatite zones are arranged in layers.[57] Lenses of lepidolite-rich pegmatite, for which the mine was operated, occur along the footwall of the core. The largest lepidolite concentrations appear to have formed at or near a bench-like roll in the dike.

The Stewart mine was opened in 1899 and was worked sporadically until 1927. Though lepidolite was its principal ore mineral, small amounts of amblygonite were also obtained. Several of its yearly outputs during this period were the largest of any lithium mine in the United States. In recent years the mine has been inactive. Much smaller amounts of lepidolite have been obtained from other pegmatites in the area, principally those at the Pala Chief, Vandenburg-Katerina, Tourmaline King, and Tourmaline Queen mines.

Uses. Lithium minerals are used as a source of lithium metal and lithium compounds, and also are employed directly as raw materials by the glass and ceramics industries. Before World War II the demand for lithia was limited, and prior to 1900 lithia was used principally in medicines and pyrotechnics. Gradually the use of lithium hydroxide in the Edison alkaline storage battery moved into first place. Today probably the largest single use is in ceramics. Lithia is an ingredient of special types of glass; these include glass with high electric resistance, glass which transmits ultraviolet light, and glass used for boiler gauges. At one time lepidolite was required in the manufacture of opaque glass. Lithium carbonate or lithium minerals are used to make glazes and enamels that have low melting points. The hygroscopic compounds lithium chloride and lithium bromide are used in air-conditioning systems. Lithium metal is a deoxidizer in nonferrous metallurgy. Lithium fluoride

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[56] See section on Gem Stones in this bulletin.

[57] Jahns, R. H., and Wright, L. A., The pegmatites of the gem and lithium districts, San Diego County, California: California Div. Mines Bull., in press.

is used to coat welding rods and lithium chloride is a flux for aluminum. Lithium metal and lithium compounds are used in organic synthesis.

During World War II, the demand for lithium increased enormously. One of the largest uses was for the lithium hydride placed in Navy emergency kits to inflate antenna balloons. Lithium glass and alloys also required large amounts. Lithium stearate lubricants were developed which are able to withstand extremes of temperature. Anhydrous lithium hydroxide was used to purify the air of submarines.

Since the war the demand has dropped, but not to the prewar level. The ceramic industry and the organic chemical industry promise to absorb increasing quantities of lithium compounds, especially if prices, compared to alternative compounds, continue to be favorable. Lithium alloys are being studied.

Before World War II the demand for lithium was sporadic, and operations were small. The irregularity of the pegmatite deposits makes exploration difficult and costly. Not often has the potential producer been able to develop enough lithium mineral to justify a consumer's adjusting his process to a new ore.

During World War II the demand increased enormously, and all possible sources of lithia were exploited. Under these favorable circumstances recovery of lithia at Searles Lake was initiated, and consumers were introduced to this unique product.

Lithium production was controlled from the end of 1942 to late 1944. Since then the price of the Searles Lake concentrate has declined, but the price of lithium minerals has risen. In 1947 dilithium sodium phosphate sold for $191 a ton. Lepidolite containing 4 percent Li_2O sold for $56 a ton.

POTASSIUM SALTS

Production of potash in California comes from a single plant at Searles Lake, and amounts to roughly 200,000 tons a year, or from 10 to 15 percent of the total United States production. California's potash production is far in excess of consumption.

The term "potash" or "actual potash," as used commercially, applies to the theoretical equivalent in K_2O content of a potassium salt. For statistical purposes, potassium compounds are dealt with on the basis of this equivalent in K_2O content. Loosely used, "potash" implies potassium salts in general.

Occurrence. Saline minerals, the geologic occurrence of which has already been described in this bulletin, are the present source of potash. Potash is recovered principally from brines and older buried deposits. Potash is also contained in several common silicates and in alunite, a basic hydrous sulfate of aluminum and potassium; but the extraction of potash from these insoluble minerals ordinarily is not practical. Both marine and land plants contain recoverable amounts. Potash becomes concentrated in the waste products of some industrial processes and at times has been recovered.

Mineralogy. The potash-bearing minerals of the Searles Lake crystal body are aphthitalite, or glaserite ($3K_2SO_4 \cdot Na_2SO_4$), with an equivalent K_2O content of 42.5 percent, and hanksite ($9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCl$) which contains 2.4 percent potassium. Elsewhere in the United States the following saline minerals are commercial sources of potash: sylvite

(KCl, equivalent K_2O content 63.1 percent), carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$, equivalent K_2O content 17.0 percent), and langbeinite ($K_2SO_4 \cdot 2MgSO_4$, equivalent K_2O content 22.6 percent).

Insoluble minerals which have been considered as sources of potash are:

Mineral	Composition	Equivalent K_2O (percent)
Alunite	$K_2Al_6 (OH)_{12}(SO_4)_4$	11.4
Glauconite	$K_2 (Mg, Fe)_2 Al_6 (Si_4O_{10})_2 (OH)_{12}$	2.3-8.5
Orthoclase	$KAlSi_3O_8$	16.8
Muscovite	$H_2KAl_3 (SiO_4)_3$	11.8
Leucite	$KAl (SiO_3)_2$	21.4

Localities. Searles Lake is the only current source of potash in California; but during the potash crisis of World War I potash was recovered from sea water bittern, kelp, cement-mill dust, and industrial waste. Bittern currently produced in the Leslie Salt Company's operations contains 1.4 percent KCl at 28° Baumé (total solids 28 percent), but it is not recovered.[58] The potash recovered from cement-mill dust by the Riverside Portland Cement Company from 1916-24 contained 11 percent K_2O.[59] Elsewhere in the United States work has been done on the recovery of alumina and potash from alunite, a basic hydrous sulfate of aluminum and potassium. Occurrences of alunite have been found near Glen Ellen, Sonoma County; Sulphur Creek, Colusa County; in the White Mountains, Mono County; and at Middle Buttes, Kern County; but potash production from any of these is not imminent.

Eighty-five percent of the United States potash production is obtained by three companies which mine bedded deposits of sylvinite (a mixture of sylvite and halite) and langbeinite in New Mexico. The world's largest potash supply is the Stassfurt deposit of Germany. Similar deposits exist in France, Poland, and Spain. Potash is also produced from the water of the Dead Sea, and Chile produces some niter (KNO_3) in connection with nitrate and iodine operations.

Uses. Ninety percent of the potash consumed in the United States is used for fertilizer. Potassium, together with phosphorous, nitrogen, calcium, magnesium, iron, and sulfur, is an essential element which a plant must obtain from the soil. The function of potassium in plants is not completely understood. Although it forms no part of the plant structure, it has a vital role as a balancer, regulator, and transporter in the synthesis of the carbohydrates and proteins which make up the parts of the plant.[60] Lack of sufficient potassium results in small, ill-formed plants that have low resistance to disease and rot. The leaves of fruit trees tend to be small, yellow, and curled. Twigs and branches die, and the fruit is small and shrivelled.[61]

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[58] Buchen, J. C., Evaporating salt from the world's largest mineral deposit: Mining and Metallurgy, vol. 18, no. 367, p. 338, August 1937.

[59] Bradley, W. W., Potash: California Min. Bur. Bull. 74, p. 112, 1917.

[60] Kutnewsky, Fremont, Potash—plant food and chemical tool box, reprint from Compressed Air Magazine, May 1943, distributed by American Potash Institute.

[61] Chapman, H. D., and Brown, S. M., Potash in relation to citrus nutrition: Soil Sci., vol. 55, no. 1, pp. 87-100, January 1943. Also paper no. 476, University of California Citrus Experiment Station, Riverside, California.

Soils which have been intensively farmed become deficient in potassium. Although some California soils are naturally low in potassium, few areas in the state have yet been farmed enough to result in a potassium deficiency.[62] The potassium of soils exists in three forms:[63] (1) Some potassium is contained in unweathered silicate minerals such as orthoclase and muscovite; this potassium is very slowly released by weathering; (2) Some potassium is dissolved in the soil moisture and is immediately available to plants; (3) Important quantities adhere to the surface of the colloids present in the soil. Much evidence indicates that by some way not completely understood the plant can absorb at least part of the potassium on colloid surfaces if the roots come in direct contact with it.

A soluble potassium compound added to a potassium-deficient soil reacts with the soil colloids. Much of the soluble potassium adheres to the colloid surfaces and is thus withdrawn from the soil moisture. The extent of this reaction depends in large measure on the soil type, and in very heavy soils most of the added potassium may be withdrawn from solution within a few inches of the surface. Plants with shallow roots may be able to absorb this colloid-held potassium, but for deep-rooted plants, such as fruit trees, the effective addition of potassium may be a difficult problem.

The potassium requirements of a given soil depend not only on the type of soil but on the kind of crop, climatic conditions, and what has previously been done with the soil. As yet there has been found no simple method to determine the amount of potassium that should be added to a soil.

Almost all the potassium used in agriculture is applied as an ingredient in mixed fertilizers. Numerous mixtures are available, but the average plant-food content of mixed fertilizers used in the United States in 1943 was potash, 7.20 percent; phosphoric acid, 9.90 percent; and nitrogen, 3.20 percent.[64] Potassium chloride is the potassium material usually used, but for some crops, particularly tobacco, potassium sulfate is preferred.

Uses by the chemical industry, though overshadowed by agricultural uses, are important. Not only does the potash chemical industry antedate the fertilizer industry, but it is among the oldest of the chemical industries. The principal potash chemicals produced are potassium chloride, potassium sulfate, and potassium chlorate. Much of the potassium chloride of chemical grade goes to the electrochemical industry for conversion to potassium hydroxide and potassium carbonate.

Potassium compounds are in general similar to the less expensive sodium compounds, but for many purposes their ease of handling, stability, solubility, crystal form, or other properties make them preferable. Large quantities of both potassium hydroxide and potassium sulfate are used in preparing soap. The best quality optical glass, colored glass, and plate glass contain potassium oxide. Potash glass is used for fluorescent light tubes.

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[62] Hoagland, D. R., Fertilizers, soil analysis, and plant nutrition: California Agr. Exp. Sta. Circ. 367, pp. 7-8, March 1947.

[63] Burd, J. S., and Stout, P. R., The soil as a medium for plant growth: Univ. California Syllabus Ser., Syllabus R U, pp. 84-85, August 1947.

[64] Turrentine, J. W., Past consumption and future (1950) requirements of potash salts in American agriculture: Am. Potash Inst., p. 5, Washington, 1946.

Explosives and pyrotechnics require additional quantities: potassium nitrate is an essential ingredient of black powder; potassium chlorate and potassium bichromate are used in the manufacture of matches. There are in addition dozens of commercial potassium salts which are used in smaller amounts.

Economic Factors. Most of the potash used in agriculture is consumed by eastern farms in the form of mixed fertilizer. Mixing plants are located near farming regions, and producers ship concentrated potash to them. Only a small part of the cost of a mixed fertilizer delivered to the farmer is represented by the price of potash.[65] Over a period of years it has been shown that demand for potash is but little affected by its price, because the demand for fertilizer, and consequently for potash, is closely related to farm prosperity. Agricultural studies show that far less than optimum amounts of potash are being used, and efforts are being made by a host of agencies to instruct the farmer in proper fertilizing practice. It is thought, however, that an increase in the demand will depend in large measure on farm prosperity.

Because of the vital importance of potash in agriculture, the Federal government has maintained close control of the potash industry. Permits are required for prospecting on public land, and deposits found are leased to operators. Usually prospecting is restricted in order to avoid overproduction. Leases require a royalty of one-tenth of the production.

At present the American potash industry is supplying the needs of the United States and exporting an appreciable surplus. As yet imports remain insignificant, for most of the potash produced in foreign countries is consumed abroad. It is felt by some that, in the interests of international prosperity, substantial imports are to be expected.

History. The United States, although once an exporter of potash made from wood ashes, was almost entirely dependent on imports of potash from Germany in 1910. When in May of that year the German government assumed control of the German potash industry, Americans generally became alarmed at being so dependent on a hostile power. The United States Geological Survey was flooded with requests for information about potash, and early the following year Congress authorized the Geological Survey and the Bureau of Chemistry to conduct field and laboratory investigations.

The two agencies working in close cooperation, attacked the problem along several lines. Perhaps their greatest contribution, besides a better understanding of the occurrence of salines, was in making the public conscious of the potash problem through the distribution of articles, the free analysis of samples, and later the field study of deposits at the request of individuals.

They did not stop with this, however. First a deep boring program was initiated in the Great Basin in order to find the massive bedded deposits of potassium salts which both Russell [66] and Gilbert [67] believed should be there. None of this work was done in California, nor did this line of reasoning bear fruit until long after the World War I potash emergency was over.

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[65] Turrentine, J. W., op. cit., pp. 5, 6, and 8.

[66] Russell, I. C., Geological history of Lake Lahontan: U. S. Geol. Survey Mon. 11, pp. 223-230, 1885.

[67] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 208, 209, 1890.

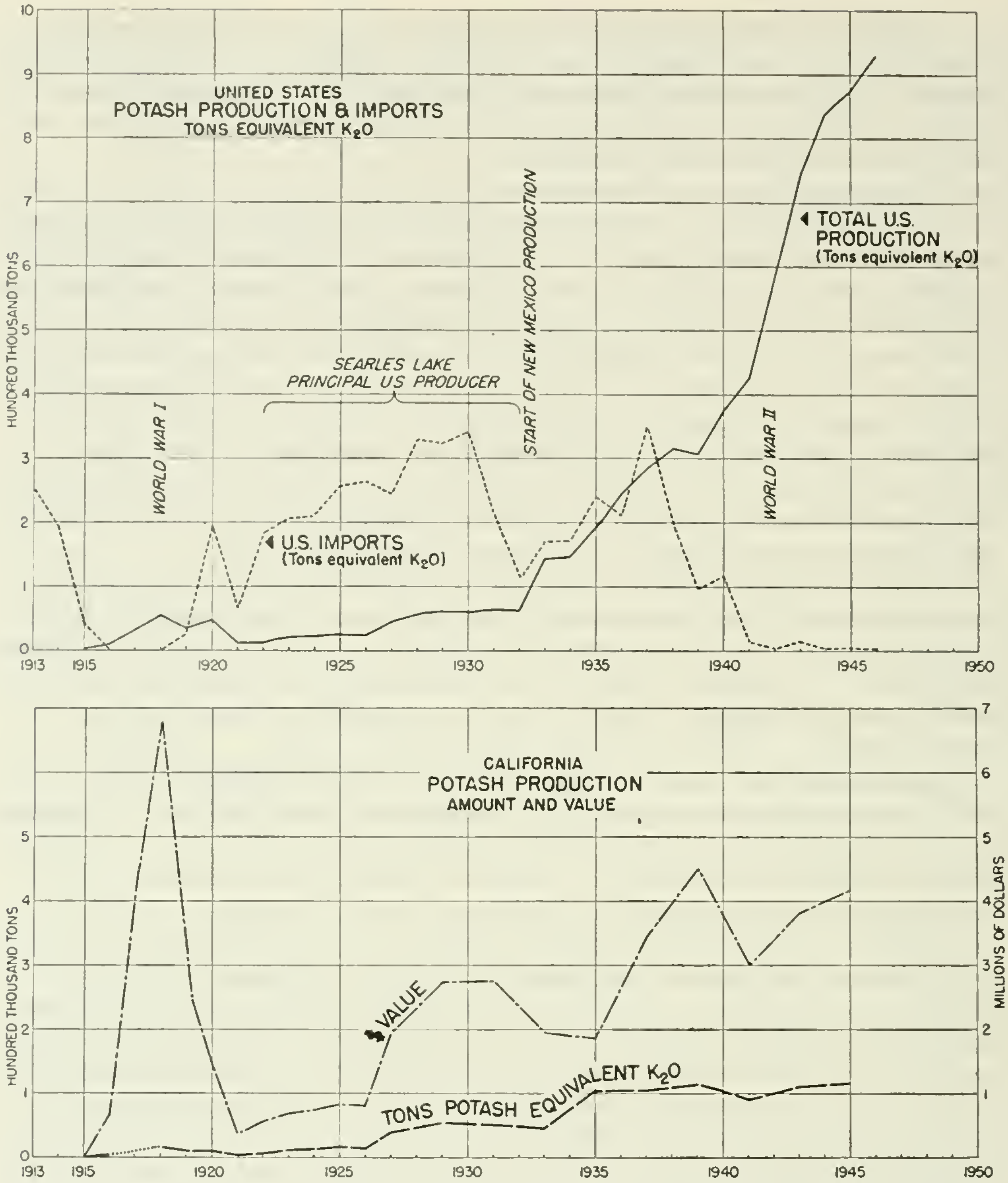

Figure 7. Chart showing total United States production and imports of potash, 1913-46 (upper graph); and amount and value of potash produced in California, 1915-45 (lower graph). K_2O equivalent estimated, 1915-45; points on the curves for the years 1928-45 represent 2-year averages.

Of more immediate interest to Californians were the field studies of the desert lakes and playas. Much of the California work was done by Hoyt S. Gale of the United States Geological Survey. Early in the program Gale and E. E. Free of the United States Bureau of Soils collected and analyzed samples of the brine from Searles Lake. The public announcement in March 1912 of the quantity of potash found, created renewed interest in Searles Lake, which had long been known for its borax and sodium salts.

As early as 1898, Whitman Symmes, superintendent of the California Borax Company, considered recovering potash from Searles Lake.[68]

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[68] Gale, H. S., Searles Lake: Mineral Resources U. S., 1912, pt. 2, p. 885, 1913.

In the hope of finding another Searles Lake among the desert playas, the search went on. By 1916 most of the saline deposits had been examined, sampled, and described. The list included, in addition to Searles Lake, Owens Lake, Cane Lake (now Koehn Lake), Roderiquez Lake (now Rogers or Muroc Dry Lake), Cadiz Lake, Bristol Lake, Amboy Lake, Salton Sink, Panamint Valley, Saline Valley, Eureka Valley, Death Valley, Mono Lake, and Carizzo Plain.[69] Except for Owens Lake the results were not encouraging, yet efforts by local men and outside companies to develop potash began early and were given up reluctantly. In Death Valley the first claims were filed in April 1912. That winter four wells were drilled by the United States Geological Survey and three more were drilled the next year by the United States Borax Company, but no high concentrations of potash were found. In 1915 a Michigan company planned to treat the weak brine by solar evaporation, but the project was abandoned.

Near Zabriskie in the Amargosa Valley early sampling indicated the presence of potassium nitrate in the surface soil of the clay hills, but subsequent testing by the Pacific Exploration Company, the Geological Survey, and others failed to confirm the early expectations.

Drilling in Rogers Lake and Cadiz Lake by Los Angeles interests was equally disappointing. The work at Cadiz Lake brought out, however, the high concentration of chlorides in the brine, and indicated that Cadiz Lake might be a source of calcium chloride.[70]

Meanwhile the Bureau of Soils was studying an entirely different source of potash: kelp, which grows on rocky coasts. Although the use of sea weed as a source of soda and potash in Europe dates back to 1720,[71] little attention was paid to kelp on the Pacific Coast until 1911. Preliminary studies determined the kinds of kelp with the highest potash content, the quantity available, and the location of the kelp beds. The greatest concentration was near San Diego. Laboratory and pilot-plant tests to find ways of using kelp were conducted by the Bureau of Soils. These culminated in the building of the Experimental Kelp Potash Plant at Summerland in 1917, where potassium salts and also iodine, activated carbon, ammonia, oils, and other products were produced by the destructive distillation of kelp.[72]

Other projects involved the study of silicates high in potash and the recovery of potash from cement-mill dust, beet-sugar refinery waste, and other industrial wastes, but pioneering work on these processes was done outside of California.

Government participation in the search for potash reached its peak about 1913, but continued for several years at a decreasing rate. The ground had been well prepared for private individuals to step in when the World War began and imports were cut off. Every possible source of potash was studied. Lake brines, saline crusts, salt-works bittern, kelp, alunite, leucite, cement-mill dust, wool scourings, smelter slag, and sugar-refinery waste are some of the sources that were developed.

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[69] Gale, H. S., Potash: Mineral Resources U. S., 1916, pt. 2, p. 108, 1919.

[70] Gale, H. S., and Hicks, W. B., Potash: Mineral Resources U. S., 1917, pt. 2, pp. 414-419, 1920.

[71] Armstrong, E. F., and Miall, L. M., Raw materials from the sea, p. 120, Brooklyn, Chemical Publishing Co., 1946.

[72] Tressler, D. K., Marine products of commerce, pp. 102, 103, New York, Chemical Catalog Co., 1923.

The kelp industry won the race to get into production. A production of 10 tons in 1914 increased 100 fold in 1915. By-product potash was produced in 1915 by the Riverside Portland Cement Company. Production at Searles Lake began in 1916, and in the same year the Whitney Chemical Company, a subsidiary of the Leslie Salt Refining Company, produced potash from salt-works bittern. The Oliver Chemical Company followed in 1917. In 1918 twenty-one California plants produced 34 percent of the domestic production, and Searles Lake had grown to be the second largest single source in the country. The California plants included two using the complex Searles Lake brine, two using sea water bittern, three cement-mill operations, seven producers from kelp, two using molasses-distillery waste, three using beet-sugar waste, and one which was leaching trash dumps.

The potash made during World War I was low-grade material produced at high cost. When foreign potash again was available these high-cost, inefficient plants were shut down. The American Potash and Chemical Corporation initiated an exhaustive research program, and solved the problem of treating the complex Searles Lake brine. A new plant was opened in 1922 and has operated successfully ever since.

SALT

Common salt (NaCl) is a basic material for human existence as well as for the chemical industry. The state's 1947 contribution of more than three-quarters of a million tons, valued at nearly $4,000,000 was about 5 percent of the total United States production.

Geology and Localities. Salt is found dissolved in sea water, saline lakes, and brines; it also occurs as rock salt in bedded deposits, in salt domes, and in the crusts of playa lakes. Rock-salt deposits, some of which are thousands of feet thick, supply most of the salt produced in the United States, but 90 percent of California's production is obtained by the solar evaporation of sea water.

Halite, the natural sodium chloride, most commonly crystallizes as cubes or in granular masses. The mineral is white when pure; traces of impurities make it yellowish, brownish, or purplish. Unlike many minerals the solubility changes very little with temperature.

California is one of the few places in the United States where proximity to markets, a dry climate with high evaporation, and land suitable for the construction of evaporating ponds are combined to make the historic solar-evaporation process still economically feasible. The industry is now centered on the southeast shore of San Francisco Bay, but some salt is similarly obtained from Monterey Bay, Newport Bay, and San Diego Bay.

A minor proportion of California salt production comes from the desert regions where large reserves occur in brines of undrained basins, in deposits on or near the surfaces of playa lakes, and in bedded Tertiary deposits which are highly deformed. Brines of the Salton Sea in Imperial and Riverside Counties, and of Dale Lake in San Bernardino County, currently provide salt. The playas at Saltdale, Kern County, and Bristol Lake, San Bernardino County, are contributing salt from a saline crust and from a crystal body respectively. Near-surface playa salt deposits at Cadiz Lake, San Bernardino County and Saline Lake,[73] Inyo County,

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[73] Gale, H. S., Salt, borax, and potash in Saline Valley, Inyo County, California: U. S. Geol. Survey Bull. 540, pp. 416-419, 1914.

have been worked in the past but are now inactive. Similar deposits in the Death Valley and Salt Wells Valley playas of Inyo County, have been exploited on a limited scale.

Tertiary lake beds in the northern foothills of the Avawatz Mountains, San Bernardino County, contain large rock-salt reserves associated with gypsum. These beds, involved in the complex structure of the Garlock and related faults, have been sampled and partially explored, but have not yet been actively worked.

Small quantities of salt have also been obtained by evaporation of natural brines other than sea water and by evaporation of brines in desert basins. Such operations included those evaporating waste water from a gas well near Suisun, Solano County,[74] saline water from springs near Sites, Colusa County,[75] and alkaline water in Surprise Valley, Modoc County. For many years the Surprise Valley operation provided a regular, but small, output. However, production was suspended in 1943.

Uses. Salt is the principal raw material from which sodium and chlorine products are made, although in California natural sodium sulfate and sodium carbonate are an additional source of sodium compounds. Sixty percent of the salt produced in the United States is used in unrefined form by the chemical industry.

Uses requiring semi-refined salt consume 20 percent of the national output. These include the packing of meat and fish, the processing of vegetable oils, the salting of hides, the regeneration of zeolite used for water softening, dust and ice control by highways and railways, refrigeration, and the construction of secondary roads.[76]

The remainder of the salt produced is highly refined. About 4 percent is used for table salt; the rest is consumed by canneries, bakeries, and in preparing dairy products.

These consumption proportions are closely approximated in California. The largest producer reports [77] that 60 percent of the production is crude salt sold in bulk to chemical plants, 15 percent is kiln-dried, semi-refined salt sold to meat and fish packers, and 12 percent is refined salt manufactured by the vacuum process. A small percentage is formed into salt blocks of two sizes for cattle and small animals.

Of historic importance is the use of salt in the metallurgy of silver. In the treatment of Comstock ores by the Washoe process, salt was one of the ingredients added to the amalgamating pan. At a later date silver ores were given a chloridizing roast prior to amalgamation or lixiviation.[78]

Markets. Probably one-third of the California salt production is shipped out of the state.[79] There is a wide range between the value of crude salt and the price of refined products. In California the average value of crude salt was $2.85 per ton f.o.b. plant in 1946.[80] According to the Oil, Paint, and Drug Reporter the price was $14.20 per ton for rock

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[74] Bradley, W. W., Solano County: California Min. Bur. Rept. 14, pp. 312, 313, 1916.

[75] Watts, W. L., Colusa County: California Min. Bur. Rept. 11, p. 180, 1893.

[76] Ries, H., Use of sodium chloride in road stabilization: Am. Inst. Min. Met. Eng. Trans., vol. 129, pp. 432-438, 1938.

[77] See, D. S., The salt industry: Unpublished paper presented at the Pacific Chemical Exposition, San Francisco, Oct. 23, 1947.

[78] Collins, H. F., The metallurgy of lead and silver, 352 pp., London, Griffin & Co., 1900.

[79] The Minerals Yearbook 1946 reports that 430,870 tons were shipped to destinations in California, compared to 796,761 tons produced. Much of this was exported.

[80] Averill, C. V., and others, California mineral production for 1946: California Div. Mines Bull. 139, p. 146, 1948.

salt in carlots and $15.70 per ton for vacuum salt in carlots, delivered in New York City.

The tariff on imports of crude salt for most uses is 6 cents a bushel; salt imported for curing meat and fish is duty free. Small quantities of salt are occasionally imported by the Pacific Coast fish industry.

Methods of Recovery. The operation of the Leslie Salt Company at Newark, Alameda County, is typical of the modern solar-evaporation method. Bay water, which contains between 3.0 and 3.5 percent salt, is admitted through tidal gates into the first of a series of 10 concentrating ponds. Brine in the last pond contains about 26.5 percent salt. After the winter rains the concentrated brine is passed into crystallizing ponds where salt crystallizes and falls to the bottom. The concentration is allowed to increase until the brine is saturated with undesired salts of calcium and magnesium. This liquid, known as bittern, is then drawn off and replaced with fresh concentrated brine.

Crude salt is harvested from September to late December. After the bittern is drained from the crystallizing ponds the salt is broken up and loaded into cars by machines mounted on caterpillar treads. The crude salt is washed first with brine and then with fresh water before it is stock piled. This material contains 99.30 percent NaCl. Much salt is sold in bulk directly from the stock pile. Semi-refined salt containing 99.80 per-

FIGURE 8. Chart showing amount and value of crude salt produced in California, 1860-1947.

cent NaCl is produced by successive kiln drying and screening. In making refined salt, crude material is dissolved in distilled water, treated chemically, and evaporated in a triple effect evaporator. The crystals formed are dewatered, dried, screened, and packed. Vacuum-refined salt contains 99.90 percent NaCl.[81]

The operations of the Dale Chemical Corporation at Dale Lake are discussed in the section on sodium sulfate in this bulletin. Lake brine is first treated to recover sodium sulfate and is further evaporated to precipitate salt.

At Bristol Lake a bed of salt 5 feet thick lies on clay.[82] About 4 feet of overburden, consisting of sand, clay, and gypsum, is removed with a dragline before the salt is drilled, blasted, and loaded into dump cars. At the washing plant it is crushed, sized, and washed with hot brine. If required, the salt can be passed through a rotary kiln drier.

At Saltdale, Kern County, brine which lies on the surface of a playa called Dry Salt Lake is collected in ditches and evaporated in solar vats. Crude salt is harvested by hand, crushed, dried, and screened.

History of Production. The earliest white settlers in the San Francisco Bay region obtained salt from natural salt pans where it formed deposits as much as eight inches thick. When these were exhausted, artificial pans were built.

One of the earliest producers of solar salt was John Quigley who in 1862 built a plant at Alvarado.[83] By 1868, 17 companies were producing 17,000 tons a year from salt pans which lined the southeast shore of San Francisco Bay from San Leandro Creek to Centerville. Most of this salt was cleaned and ground at San Francisco.

Previous to 1882 the salt produced locally was of poor quality compared to salt imported from Liverpool and from Carmen Island, Lower California. Many of the companies operated intermittently until, with the discovery of the Comstock Lode, there was a shortage. All the salt used for ore treatment came from San Francisco.

By 1882 the quality of the local product was so much improved that imports were falling. The process of the Union Pacific Company,[84] one of the larger producers, was essentially like that used today.

Pumping was by a windmill-driven paddle wheel operating in an inclined wooden trough.[85] Archimedes screw windmills were used later in great numbers and are still to be seen. Crystallizing ponds, much smaller than those used today, were from 1 acre to 8 acres in size, and some had bottoms made of planed boards. Harvesting was entirely by hand. The salt was first shoveled into small piles and then taken in wheelbarrows to larger stacks where it remained through at least one rainy season. Table salt was evaporated in elevated wooden pans. In 1880, salt produced from San Francisco Bay water contained 99.4 percent sodium chloride.[86]

The later history of the San Francisco Bay salt industry is one of consolidation of producers. Eighteen producers reported production in

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[81] See, D. S., op. cit.

[82] Tucker, W. B., and Sampson, R. J., Mineral resources of San Bernardino County: California Div. Mines Rept. 39, p. 539, 1943.

[83] Hanks, H. G., On ~~the~~ occurrence of salt in California and its manufacture: California Min. Bur. Rept. 2, pp. 218, 219, 1882.

[84] Hanks, H. G., op. cit., pp. 221, 222.

[85] Hanks, H. G., op. cit., pp. 217, 226.

[86] Bailey, G. E., The saline deposits of California: California Min. Bur. Bull. 24, p. 114, 1902.

1900; now there are only 3. In 1901 the California Salt Company was formed and gradually acquired the plants of competitors in Alameda County. In the same year the Leslie Salt Refining Company began operations near Redwood City, San Mateo County. Salt was not produced in San Mateo County until 1900 and only three or four companies have operated there, the last of which shut down in 1940.

The Leslie-California Salt Company was incorporated in 1924 as a consolidation of the Leslie Salt Refining Company, the California Salt Company, and the Continental Salt and Chemical Company, whose works adjoined the California Salt Company near Alvarado. In 1931, Leslie-California absorbed the Oliver Salt Company which had operated since 1872. The company was re-incorporated in 1936 as the Leslie Salt Company, when it absorbed the Arden Salt Company, and with it the Union Pacific Salt Company which the Arden Company had acquired in 1926. All the early producers, with the exception of the American Salt Company founded in 1865, have been thus absorbed. The third Alameda County producer, Oliver Brothers Salt Company, is a newcomer which began producing in 1938.

Concurrent with this consolidation has been a steady evolution in technique, and improvement in the quality of the salt produced. Control of brine concentration to prevent contamination by bittern salts, the high degree of mechanization, and the vacuum-refining process introduced in 1910 are highlights.

The recovery of bittern salts was unimportant before World War I, although the Union Pacific Company was producing magnesia in 1882. It was sold to the Hercules Powder Company for use in the manufacture of explosives.[87] The shortage of chemicals during World War I created a new interest in bittern salts. Today, important chemical plants treat salt bittern produced not only in the San Francisco area but also at Moss Landing and San Diego. Products include magnesium compounds, bromine, and gypsum.

The salt deposits of the desert regions were known at an early date but little used. The Saline Valley deposit was discovered in 1864. Some salt was mined from deposits near Daggett for use in silver mines at Calico. Other salt used by silver mines came from the Surprise mines on Danby Lake, 6 miles from the south end of the Old Woman Mountains, San Bernardino County.[88] The salt was hauled 25 miles to Daggett in wagons pulled by steam traction engines.

Salt mining at Salton Sea began in 1884 and continued until the flood of 1903. The salt crust, 10 to 20 inches thick, was gathered into piles with plows. Salt was not produced again until 1929, when the salt content of the water had become high enough to permit its recovery by solar evaporation.

SODIUM CARBONATE

More than 90 percent of natural sodium carbonate produced in the United States comes from California. In normal times this production is entirely consumed by west coast industries. For the United States as a whole, however, natural sodium carbonate compounds comprise only about 5 percent of domestic production; the remainder is manufactured

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[87] Hanks, H. G., op. cit., p. 223.
[88] Bailey, G. E., op. cit., p. 128.

from common salt. Sodium carbonate compounds of commerce include soda ash (Na_2CO_3) of various grades, sal soda ($Na_2CO_3 \cdot 10H_2O$), the monohydrate ($Na_2CO_3 \cdot H_2O$), and sodium bicarbonate ($NaHCO_3$).

Geology and Mineralogy. Sodium carbonate, one of the saline minerals, is found in the brines of certain springs and saline lakes and as deposits in playa lakes. Trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) is the most common sodium carbonate mineral. It is a very soluble, gray or yellowish translucent mineral which occurs in fibrous or columnar masses or, less commonly, in cleavable plates. Natron ($Na_2CO_3 \cdot 10H_2O$) is a very soft mineral which readily dehydrates on exposure to dry air. Other less common sodium carbonate minerals are hanksite ($9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCl$), burkeite ($2Na_2SO_4 \cdot Na_2CO_3$), thermonatrite ($Na_2CO_3 \cdot H_2O$), and nahcolite ($NaHCO_3$).

Localities. All of the sodium carbonate produced in California is obtained by five plants located at Owens and Searles Lakes. Outside of California natural occurrences of sodium carbonate are rare, but it is recovered near Green River, Wyoming, both from brine and from deeply buried deposits of trona.[89]

Most of the sodium carbonate produced in the United States is made by the ammonia-soda or Solvay process, in which ammonia and salt are combined with carbon dioxide to give sodium bicarbonate and ammonium chloride. Soda ash is obtained by calcining the sodium bicarbonate. The ammonium chloride is treated with slaked lime to yield ammonia and by-product calcium chloride. The ammonia is used again. Soda ash is also manufactured by electrolysis of a salt solution. The sodium hydroxide which forms at the cathode is converted first to sodium bicarbonate with carbon dioxide and then calcined to soda ash. Chlorine is a by-product. Ammonia-soda plants are ordinarily located near supplies of both fuel and limestone.

Uses.[90] Sodium carbonate, among industrial chemicals, is second in importance only to sulfuric acid. The California output is used mainly in the glass and cleanser industries, but smaller amounts are consumed in making paper, oil refining, sugar refining, water softening, in metallurgy, and in making chemicals. In many cases the sodium carbonate is first converted to caustic soda ($NaOH$) by the consumer. Common glasses are composed principally of silica and alkali. From 14 to 18 percent of the batch is soda ash.

Soda cleansers contain an abrasive, soap, and a mixture of soda ash and caustic soda which provides a specified alkalinity. Most of the soda ash consumed in the soap industry is added to a soap solution to make granulated soap. The large quantity of caustic soda used was formerly obtained by causticizing soda ash, but present practice is to purchase caustic soda. In the paper industry ground wood pulp is digested in a concentrated solution of caustic soda, dissolving lignin and leaving fibrous cellulose. Probably about half of the soda pulp plants obtain caustic soda from soda ash, the remainder from salt. In petroleum refining, products treated with sulfuric acid are neutralized with dilute caustic soda. In water softening, soda ash precipitates soluble calcium salts, particularly the chloride.

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[89] Smith, H. I., Trona in Wyoming: Am. Inst. Min. Met. Eng. Tech. Pub. 1489, 3 pp., 1942.

[90] Harness, C. L., and Coons, A. T., Sodium carbonate: U. S. Bur. Mines Inf. Circ. 7212, pp. 9-14, 1942.

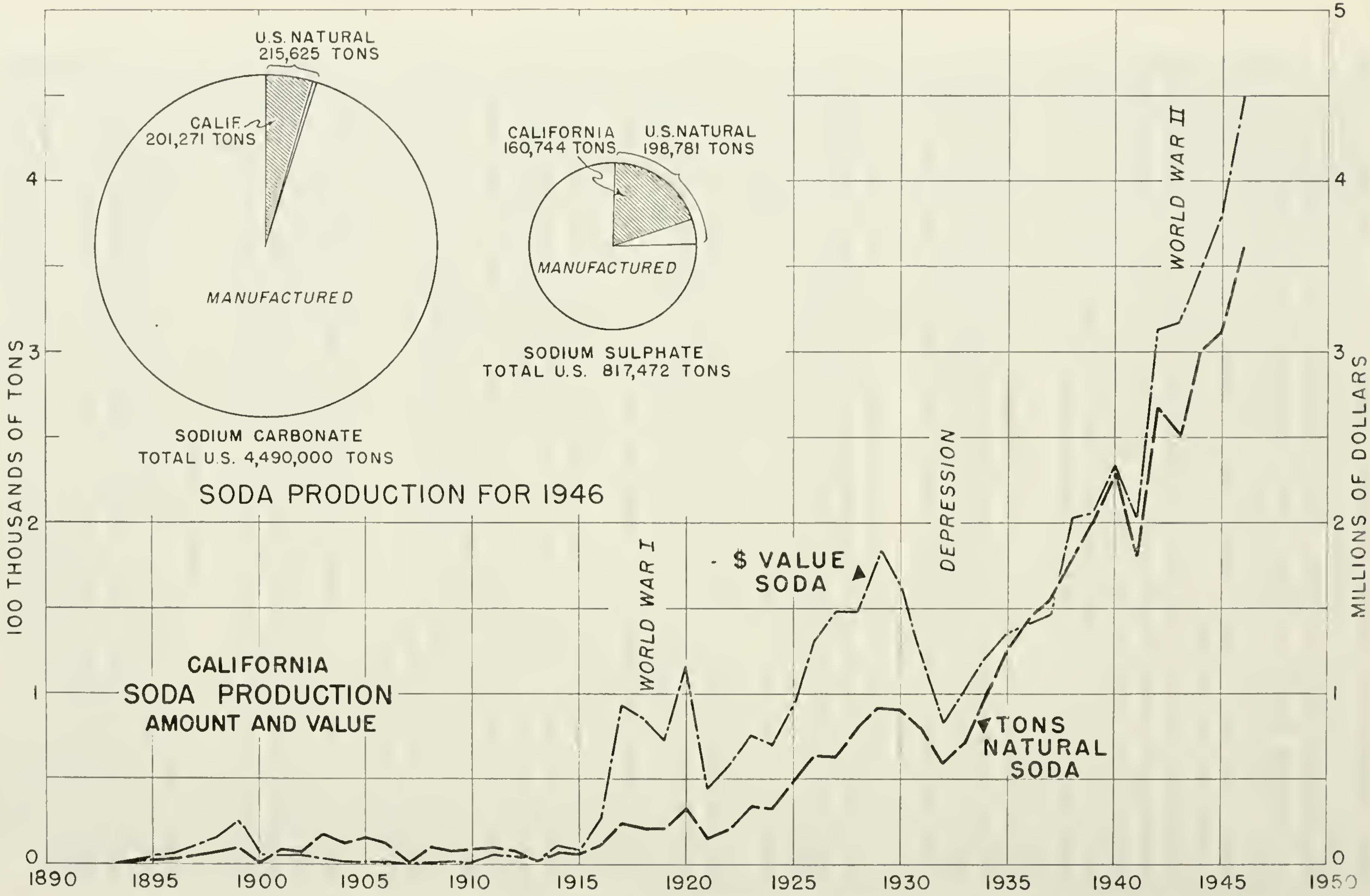

FIGURE 9. Chart showing amount and value of soda (sodium carbonate and sodium sulfate) produced in California, 1893-1946.

In metallurgy, the aluminum industry consumes the greatest tonnage of soda ash. It is causticized to caustic soda which is used to prepare the pure alumina necessary for electrolysis. Smaller quantities are used in preparing compounds of chromium, tungsten, and vanadium from their ores.

In the chemical industry soda ash is usually used for the preparation of other sodium compounds because it is comparatively cheap and because it reacts readily with other chemicals. The manufacture of caustic soda consumes about half the soda ash used by the chemical industry; other chemicals manufactured from soda ash include sodium nitrate, sodium silicates, sodium phosphates, and sodium chromates.

Prices. The prices of the various compounds differ considerably. In 1946 light calcined soda ash, sold in bags, and carlots at the works, was quoted at $1.20 a hundredweight in the east. This was slightly higher than the previous year. The price of natural soda is probably lower.

Markets. The shortage of sodium carbonate which developed all over the world during World War II was particularly severe in California. The substitution of glass for steel containers was responsible for much of the increased demand for sodium carbonate.

When materials were available, existing producers enlarged their plants, and one west coast consumer constructed his own plant on Owens Lake. The rate of production had nearly doubled that of 1944 by mid-1948 when the demand began to decline.

SODIUM SULFATE[91]

Salt cake is crude anhydrous sodium sulfate containing 92 to 99 percent Na_2SO_4. The name is also applied to deposits of the mineral thenardite. Other sodium sulfate compounds of commerce include anhydrous sodium sulfate, glauber's salt ($Na_2SO_4 \cdot 10H_2O$), and niter cake ($NaHSO_4$). California contributes about 80 percent of the total natural sodium sulfate produced in the United States. Less than 25 percent of the national consumption, however, was of the natural material.

Geologic Occurrence and Mineralogy. Natural sodium sulfate occurs in the brines and crusts of playa lakes, and as beds in sedimentary rocks.

Mirabilite ($Na_2SO_4 \cdot 10H_2O$) and thenardite (Na_2SO_4) are the common sodium sulfate minerals. Mirabilite forms needle-like crystals resembling the pyroxenes in shape. It generally occurs as crusts or efflorescences. It is a very soft, white mineral with a vitreous luster; it may be transparent or opaque. It is quite soluble in warm water but much less so in cold water. When exposed to dry air it loses its water of crystallization and falls to a fine powder.

Thenardite is a white or brownish mineral which forms both euhedral crystals and crystalline masses. It is very soluble in water. Thenardite is precipitated from a brine containing sodium sulfate, when the brine is evaporated at temperatures above 32.38° C.

Other minerals which contain sodium sulfate are glaserite ($3K_2SO_4 \cdot Na_2SO_4$), blödite ($MgSO_4 \cdot Na_2SO_4 \cdot 4H_2O$), glauberite ($Na_2SO_4 \cdot CaSO_4$), hanksite ($9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCL$), and burkeite ($2Na_2SO_4 \cdot Na_2CO_3$).

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[91] King, C. R., Soda ash and saltcake in California: California Jour. Mines and Geology, vol. 44, pp. 189-200, 1948.

Localities and Methods of Recovery. In California sodium sulfate is produced at Searles Lake by the American Potash and Chemical Corporation, and at Dale Lake, San Bernardino County, by the Dale Chemical Corporation, formerly the Desert Chemical Company. The Searles Lake operation is described in the general section of salines in this bulletin. The brine of Dale Lake, which is a playa, contains 22 percent sodium chloride and 7 percent sodium sulfate.[92]

Wells near the center of Dale Lake supply brine which is concentrated by solar evaporation during the summer, or by spraying during the winter. The concentrated brine is passed into crystallizing vats where glauber's salt forms, and the remaining liquor is further evaporated in another vat for the recovery of salt.

At the southwest end of the lake, a bed of thenardite 600 feet wide, 4000 feet long, and averaging 6 feet in thickness, is 94 percent sodium sulfate. From 6 to 8 feet of overburden consisting of sand and clay is stripped off before mining. The thenardite is washed and crushed with rolls to one-eighth inch size before shipment.

Outside of California, natural sodium sulfate was produced during 1946 in Texas, Iowa, and Wyoming, and also in Canada. It is, or has been, produced in Chile, Italy, Spain, Russia, Egypt, and parts of Asia.

Potential Sources. Two other localities, one in Imperial County and one in San Luis Obispo County, have produced sodium sulfate in the past. Shipments have been made from a deposit of thenardite in the Durmid Hills, Imperial County.[93] Here folded Tertiary clays, shales, and sandstone contain beds of thenardite associated with a minor amount of mirabilite and blödite. The sulfates are exposed over an area half a mile wide and about 3000 feet long, and beds 3 inches to 5 feet thick have been encountered. Some mining by open cut has been done, but the operation was abandoned because of the high magnesium sulfate content (4 percent).

The deposit of mirabilite in San Luis Obispo County, has also been worked on a small scale.[94] Soda Lake occupies the lowest part of Carrizo Plain, an undrained structural basin between the Caliente and Temblor Ranges. A crust of mirabilite little more than an inch thick covers an area of from 2800 to 3000 acres, but in filled channels the mirabilite may be as much as 6 feet thick. Beneath the crust is a brine-saturated, greenish-gray mud containing crystals of mirabilite and blödite. The deposit, although thin, is estimated to contain over a million tons of mirabilite. Some production was obtained by dissolving the crust, collecting the brine, and re-precipitating sodium sulfate in pans by solar evaporation.

Sodium sulfate is present at Owens Lake and Mono Lake but is not recovered commercially.

Prices. In 1946, the price of saltcake was $15 a short ton, anhydrous sodium sulfate $1.70 a hundredweight, and glauber's salt $1.05 to $1.45 a hundredweight.[95] Natural sodium sulfate usually sells for somewhat less. Prices have not changed greatly in recent years.

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[92] Tucker, W. B., and Sampson, R. J., Mineral resources of San Bernardino County: California Div. Mines Rept. 39, pp. 540, 541, 1943.

[93] Sampson, R. J., and Tucker, W. B., Mineral resources of Imperial County: California Div. Mines Rept. 38, pp. 140-143, 1942.

[94] Franke, H. A., Mines and mineral resources of San Luis Obispo County: California Div. Mines Rept. 31, pp. 455-457, 1935.

[95] Harness, C. L., and Barsigian, F. M., Sodium sulfate: Minerals Yearbook 1946, p. 748, 1948,

Uses. Sodium sulfate is one of the important industrial chemicals. The manufacture of kraft paper, glass, and chemicals consumed most of the output of the natural product; but other uses are in metallurgy, in stock feed, and in soapless detergents.

In 1946, about 80 percent of the total supply was used by the kraft paper industry. In this process sodium sulfate is reduced with carbonaceous material, usually sawdust; and the resulting solution, which contains sodium sulfide, caustic soda, and sodium carbonate, is used to separate lignin from the cellulose fibers. In Canada sodium sulfate is used in the Orford process for treating copper-nickel ores.

Heavy chemicals made from sodium sulfate are principally sodium aluminum and sodium silicates. The use of sodium sulfate in soapless detergents is new and growing. At present from 50 to 75 percent of sodium sulfate is added as a diluent, and if present methods of manufacture are not changed, this industry may consume a large proportion of the total.

History of Production. For many years the most important source of sodium sulfate was saltcake produced as a by-product in the manufacture of hydrochloric acid. This was done in two stages according to the following reactions:

$$NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$$
$$NaCl + NaHSO_4 \rightarrow Na_2SO_4 + HCl$$

Many hydrochloric acid plants used niter cake obtained from a now nearly obsolete process of making nitric acid:

$$NaNO_3 + H_2SO_4 \rightarrow HNO_3 + NaHSO_4$$

About the year 1927, plants making hydrochloric acid by the direct synthesis of chlorine and hydrogen partly displaced the salt and sulfuric acid process, while at the same time there was an increasing demand for sodium sulfate in the kraft paper industry. Imports, particularly from Germany, in part satisfied the demand. A method was developed to prepare sodium sulfate from sodium carbonate, and there was also a stimulation of interest in natural sodium sulfate both in the United States and elsewhere.

SAND AND GRAVEL

By Mort D. Turner

California, the leading state in the production of sand and gravel, yielded 33,786,520 tons of these materials in 1948. This represented about 12 percent of the national total. The state's output had a value of $30,592,965, which was surpassed only by the values of petroleum products and cement produced.[1] In recent years the production of sand and gravel in California has risen sharply. This is a direct result of the increased post-war industrial and building activity.

Approximately nine-tenths of the state's sand and gravel output is used as aggregate in construction and road building. The remainder is

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[1] Runner, D. G., and Tucker, G. E., Sand and gravel in 1948: U. S. Bur. Mines Mineral Industry Surveys, Mineral Market Rept. 1770, p. 6, 1949.
Runner, D. G., and Tucker, G. E., Sand and gravel: Minerals Yearbook 1947, pp. 1034-1048, 1949.

glass sand, foundry sand, abrasive sand, fire or furnace sand, engine sand, filter sand, and sand and gravel used as railroad ballast and railroad fill.

Sand and gravel are obtained from many widely scattered localities in the state. In 1947 active operations were reported in all but four counties (Kings, Madera, Marin, and Sierra).

Geologic Occurrence and Localities. Sand is composed of rock or mineral grains, the diameters of which have a range of 200-mesh to a quarter of an inch; gravel, of like composition, has a diameter range of a quarter of an inch to 3½ inches. Many deposits consist almost entirely of sand or of gravel but ordinarily the two are mixed and are separated at a plant. At many plants the coarser gravel is crushed and is then classified as crushed rock.

In California, sand and gravel is obtained principally from Quaternary stream deposits. Smaller though significant quantities are obtained from Recent beach and dune sands and from older sedimentary beds. The grains and fragments in all of these types of deposits have been transported and are characteristically slightly rounded to well rounded.

Stream-deposited sand and gravel are obtained from stream channels, flood plains, terraces, and alluvial fans. These deposits are typically poorly sorted and are composed of interfingering lenses elongate parallel to the direction of stream flow. In most of them the size of the sand and gravel fragments is highly variable; some have a relatively high clay content. Clay-free material is most valued for use as aggregate, but clay-bearing alluvial material, in relatively small amounts, is locally mined as foundry sand.

Stream-laid sand and gravel deposits underlie large areas of the state and constitute a virtually inexhaustible reserve. The commercial value of deposits of usable material, however, is largely determined by their distance from centers of consumption and by the ease with which they can be worked. The reserves, even within the immediate areas of many plants, are not wasting, but are continually being replenished by streams during the rainy season.

In northern California, stream-laid deposits, from which aggregate sands and gravels are obtained in large quantity, are in the Livermore Valley and Niles area, Alameda County; the Oroville area, Butte County, where dredge tailings are being worked; areas along the Sacramento River in Colusa and Shasta Counties; the Red Bluff area, Tehama County; areas along the American River near Sacramento, and the Perkins area, Sacramento County. Smaller amounts of material are removed from deposits along Cache and Putah Creeks in Yolo County.

Sand and gravel aggregate operations in the San Joaquin Valley are located along the San Joaquin River and its tributaries at Tracy and Riverbank, San Joaquin County; in the Modesto area and at several other localities in Stanislaus County; in the Merced area, Merced County; and at numerous localities in Fresno, Tulare, and Kern Counties.

Los Angeles County, which yields over one-third of the sand and gravel aggregate produced in California, has the largest output of any county in the state. The principal sources are along the Los Angeles, Big Tujunga, and San Gabriel Rivers and the Rio Hondo.

Other sand and gravel aggregate operations in southern California are along the Sweetwater, Otay, and San Diego Rivers, San Diego County; near San Bernardino, San Bernardino County; and in northeastern Riverside County.

Several of the plants operating in stream-deposited gravels are extracting gold from the aggregate during washing. The largest of these plants are at Friant in Fresno County, Azusa in Los Angeles County, and Fair Oaks in Sacramento County.

Clay-bearing alluvial material that is mined as naturally bonded foundry sand is obtained from deposits in the San Francisco, Sacramento, Riverside, Torrance, Redondo, and central Los Angeles areas.[2]

Beach sand and near-shore dune sand deposits contribute less than 2 percent of the total sand and gravel output in California. These, however, are the state's chief source of specialty sands, such as those used in foundry molds, in glass manufacture, and as sand-blasting material. These command a higher average price than those used for aggregate. Nevertheless, much of the dune and beach sand output is also used as aggregate material.

Because beach sands were originally deposited by water and have been reworked by wave and current action, they are generally composed of a much more uniform and better sorted material than that of the average stream deposit. Like stream deposits, however, their composition is determined by the nature of the bedrock from which they were derived. The well-known beach and dune sands at Moss Beach west of Pacific Grove, Monterey County, were derived almost entirely from granitic rocks; consequently they are composed principally of quartz and feldspar in an unusually clean mixture.

At many points along the California coast, particularly in northern California, beach and dune sands have been derived largely from basic igneous rock and from shales and sandstones rich in ferromagnesian minerals. Such sands are useless as glass sands, and are of much less value as foundry sand or sandblasting material than, for example, the sands of Moss Beach.

Most of the beach and dune sand produced in California is obtained from the Monterey Bay area. Commercial sands are also obtained from beaches and dunes in the San Francisco, Oceano, and El Segundo areas.[3]

Certain beach deposits in both northern and southern California are rich in heavy minerals such as magnetite (Fe_3O_4), ilmenite ($FeTiO_3$), and chromite ($FeCr_2O_4$). These are discussed in the section on black sands in this volume.

Although most of the sand and gravel produced in California is obtained from deposits of the most recent geologic period (Quaternary), a significant volume is obtained from partly consolidated Tertiary sediments. Materials from these sources ordinarily contain a larger silt and clay fraction than the average alluvial, beach, or dune deposit. Usable Tertiary deposits are, in general, farther removed from centers of consumption than Quaternary alluvial deposits and ordinarily they are moderately to highly deformed. They do constitute, however, a very large reserve of well-sorted uniform sand. Some of these deposits constitute the only known sources of high-silica sands in California.

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[2] Wright, L. A., California foundry sands: California Jour. Mines and Geology, vol. 44, pp. 36-72, 1948.

[3] Wright, L. A., op. cit.

Upper Miocene feldspathic sandstones near Felton, Santa Cruz County, are mined principally as aggregate material, as are Eocene beds east of Oceanside, San Diego County. Clay-free, high-silica foundry sand is obtained from open-pit and underground workings in Eocene beds in the old Nortonville-Somersville coal-mining area in Contra Costa County. A clay-silica sand, "ganister," is obtained from Eocene beds in the Tesla coal-mining area, Alameda County.[4] An Eocene deposit south of Corona, Riverside County, is a source of glass sand.

Clay-bearing (naturally bonded) foundry sands are obtained from Pliocene beds west of Millbrae, San Mateo County; from Pleistocene beds in Ventura, Ventura County; and from Pliocene beds in San Diego, San Diego County.

Utilization. Approximately nine-tenths of the sand and gravel produced in California is marketed as aggregate. Quaternary stream deposits are the principal source. A relatively small volume is obtained from beach and dune sands and from Tertiary sedimentary beds.

In 1947 the sand and gravel aggregate produced in California for use in the building industry totaled 17,489,643 tons, valued at $14,137,450. The output consumed as paving material totaled 13,139,344 tons, valued at $10,022,639.

To assure a good bond with its binder, aggregate should contain no clay or silt. Most of the binder used in building is portland cement or lime. In paving, a large volume of aggregate is used with portland cement, but even greater amounts have bituminous binders, such as asphalt. A maximum strength in concrete depends in part upon the use of an aggregate with an optimum size range. A concrete which is to have great strength must contain an aggregate composed of strong mineral and rock fragments, and one that is free from minerals that will react with the cement.

The known reactive minerals include gypsum, zeolite, pyrite, opal, and chalcedony. The reactions cause internal stresses that commonly result in marked loss in strength and the development of pits, known as "popouts," on the concrete surface. Rhoades and Mielenz[5] have discussed reactive minerals in aggregates and have referred specifically to California sand and gravel sources and to structures in the state containing reactive aggregate.

Aggregate grains should not be highly porous, but a slight porosity is desirable to give bonding strength. Most structures are designed to employ aggregate of a specified density. Aggregate used in paving of either the concrete or bituminous type must have the additional property of resistance to degradation.

A sand and gravel aggregate plant is essentially a washing and sizing operation. In the simplest procedure, the material is washed only. Some operations involve a two-fold splitting into sand and gravel sizes; others produce four or more sizes. Where there is a surplus of large material, it is commonly crushed to usable size. Separate sizes are marketed as such or are blended to meet specifications of the users.

Approximately 0.5 percent of the sand and gravel produced in California is used as railroad ballast or railroad fill. The importance of

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[4] Wright, L. A., op. cit.

[5] Rhoades, R., and Mielenz, R. C., Petrographic and mineralogic characteristics of aggregates, symposium on mineral aggregates (1948): Soc. Testing Materials Special Tech. Pub. 83, pp. 39-47, 1948.

ballast in rail transportation is indicated by the following functions as listed by Goldbeck.[6]

> "1. It supports the ties and also resists their horizontal movement due to the action of traffic and of temperature changes in the rails.
> 2. It distributes the wheel loads and thus reduces the pressure intensity on the roadbed.
> 3. It provides a means for draining water from under the ties.
> 4. It provides a ready means for surfacing the track and keeping it in proper alignment and grade.
> 5. It provides a non-rigid foundation for the track and thus reduces the destructive effect of unbalanced moving parts in the rolling equipment; it aids in reducing the shocks of traffic on the track.
> 6. It retards the growth of vegetation."

Railroad ballast must resist weathering and impact. Ballast composed of uncrushed gravel generally contains a high sand fraction to give added stability; less sand is needed when crushed gravel is used.

Most of the railroad companies operate their own ballast pits, but they also obtain material from other aggregate operations. Some of the larger ballast gravel pits are at Forbes, Los Angeles County, and at Newberry and Baxter, San Bernardino County.

Sands produced for foundry use in molds are of two principal types; clay-free and naturally bonded (clay-bearing) sands. The clay-free sands are used as a base for synthetically prepared foundry sands which contain refractory clay as an added constituent. Naturally bonded sands are natural mixtures of sand and clay, and generally are not blended with other sands or clays. The hollow spaces within the molds are occupied by cores composed of moist mixtures of sand with various organic materials and binders. Core sands are clay-free.[7]

Synthetically prepared sands, which allow a greater control in mold preparation and permit the use of more refractory molds than do naturally bonded sands, are being used in increasing volume. Naturally bonded sands, however, are still widely used in the preparation of low-temperature castings, and are less expensive.

Steel castings require a sand particularly high in silica. The feldspathic foundry sands which are produced along the California coast at San Francisco, Monterey Bay, Oceano, and El Segundo are, therefore, unsuited to steel casting. The only high-silica sands known in California are confined to Paleocene and Eocene formations. Of these, the only deposits currently contributing sands to steel foundries are those in the Nortonville-Somersville area, Contra Costa County.

Naturally bonded sands are obtained from alluvium in the Sacramento, San Francisco, Los Angeles, Torrance, Redondo, and Riverside areas, and from Tertiary sediments in the Millbrae, Ventura, Santa Ana, and San Diego areas.

A refractory, clay-sand mixture, incorrectly known as "ganister" is obtained from an Eocene deposit in the old Tesla coal-mining area, Alameda County, and from Paleocene deposits, that also yield china clay, in the Trabuco Canyon area, Orange County.

Virtually all of the abrasive sand produced in California is marketed for use in sand-blasting equipment. The beach and dune deposits of Mon-

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[6] Goldbeck, A. T., Mineral aggregates for railroad ballast, symposium on mineral aggregates (1948): Am. Soc. Testing Materials Special Tech. Pub. 83, p. 199, 1948.

[7] Ries, Heinrich, Properties of foundry sands: California Jour. Mines and Geology, vol. 44, pp. 9-35, 1949.

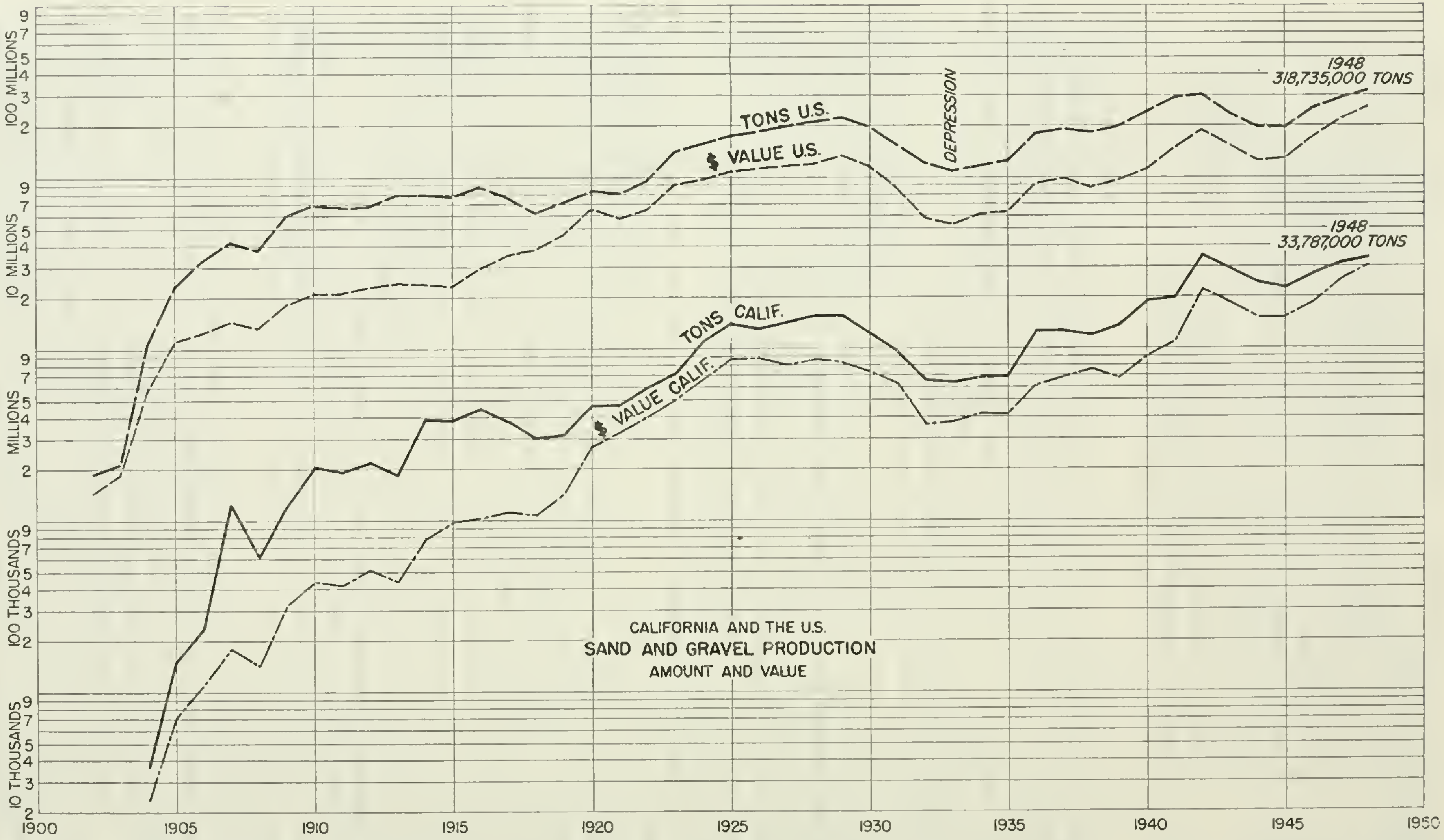

FIGURE 1. Chart showing amount and value of sand and gravel produced in California, 1904-48, and in the United States, 1902-48.

terey Bay are the principal sources, but an appreciable output is also obtained from El Segundo area. Abrasive sands are discussed more fully in the section on abrasives in this bulletin.

Sand used in the manufacture of glass is currently obtained from beach and dune-sand deposits in the Moss Beach area west of Pacific Grove, Monterey County, and from a Paleocene sand deposit south of Corona, Riverside County.

Two operations are at Moss Beach. The entire output of one is consumed in glass manufacture, and most of the output of the other is similarly used. These sands, which contain approximately 40 percent feldspar, are first washed and screened; organic matter and some of the iron oxide and ferromagnesian material are removed by tabling. The sand is then dried and most of the remaining iron-bearing grains are removed by magnetic separation.

The operation south of Corona obtains sand from Paleocene sandstone, of which approximately 40 percent is clay and silt. This fraction is removed by washing and scrubbing. The sand is dried and most of the iron-bearing grains are magnetically separated. The product is a clean, high-silica sand.

In the past, glass has also been manufactured from sands obtained from Eocene beds near Lincoln, Placer County; Ione, Amador County; and from areas in eastern Alameda County and northern Contra Costa County.[8] Most of the production from these sources was obtained previous to World War I, but the Contra Costa County deposits were worked for glass sand as late as 1946.

All of the glass sand now produced in California is being used in the manufacture of clear and colored bottle ware, although some early production from Monterey[9] and Amador Counties went into window glass.

In 1947, California produced 5907 tons of sand which was marketed for use in filters. This output was valued at $41,263. Filter sand is used to remove sediment and bacteria from water. City water departments are the principal users. Nearly any clean sand, of a proper size range and composed either of angular or rounded water-resistant grains, is suitable; but high-silica sands are apparently preferred. Most of the filter sands are obtained from the beach and dune-sand deposits that supply clay-free foundry sands.

In 1947, California produced 39,565 tons of engine sand, which was valued at $21,931. Engine sand is used to increase the friction and reduce slippage under the drive wheels of locomotives and streetcars. For such use a high-silica, free-flowing sand is preferred. Most of the output in California is obtained from the dune and beach-sand deposits that furnish clay-free foundry sands.

Mining Methods. Because sands and gravels are generally large-volume products of low unit price, the expense of mining must be correspondingly low. Only with certain relatively high-priced specialty sands are underground operations justifiable. Underground methods are

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[8] Dietrich, W. F., The clay resources and the ceramic industry of California: California Min. Bur. Bull. 99, pp. 33-63, 1928.
Huey, A. S., Geology of the Tesla quadrangle, California: California Div. Mines Bull. 140, pp. 33-38, 60, 1948.

[9] Aubury, L. E., The structural and industrial materials of California: California Min. Bur. Bull. 38, p. 279, 1906.

employed at the "ganister" operation at Tesla and at a foundry-sand operation in Nortonville-Somersville area, Contra Costa County. All other sand and gravel operations in the state employ surface methods and use a wide variety of equipment.

Prices and Markets. Though the production of sand and gravel has risen sharply in California from more than 27 million tons in 1946 to nearly 34 million tons in 1948, the average value per ton has shown an even greater increase from 68 cents to 91 cents. In 1948, producers valued aggregate sand and gravel at the pit at approximately 35 cents to $2 per ton. Specialty sands were valued at $4.50 per ton. The trend in sand and gravel production in California has nearly paralleled that of the United States as a whole, as may be seen on the accompanying graph. The great production peaks were in 1917 and 1942, during the emergencies of World Wars I and II; during the postwar period of private building from 1925-29; and during the present postwar period.

Very little gravel is shipped into or out of the state with the exception of some of the special sands. Glass and foundry sand obtained near Lake Mead, Nevada, is extensively used in California, and zircon sand from Florida for foundry uses is finding an increasing market in the state.

SLATE

By Mort D. Turner

Slate has been intermittently produced in California since soon after the gold rush days. The peak recorded annual productions of approximately 10,000 squares[1] were obtained in 1903 and 1906. Although the industry was nearly dormant for many years, a revival during World War II led to yearly outputs comparable to the previous high. Most of the recent production has come from a single property in El Dorado County.

General Geology. Most of the slate produced in California has been obtained from the Jurassic Mariposa formation, which is exposed in the western foothill belt of the Sierra Nevada. Originally the Mariposa formation was a marine shale, with minor amounts of conglomerate and sandstone interbedded in it. Near the close of the Jurassic period it was folded, and locally intruded by granitic rocks. The pressure and heat acting upon the shaly material resulted in partial recrystallization forming platy, micaceous minerals in a parallel orientation sufficiently well developed to allow easy splitting. The minerals that form the mass of the rock are the mica, muscovite $[(K,Na)(Al,Mg)(Si,Al)_4O_{10}(OH)_2]$; quartz (SiO_2); and graphite (C). Pyrite (FeS_2) is locally present in sufficient quantities to produce yellow-brown iron-oxide stains when the slate is exposed to weathering.

Localities. California's entire production of slate has come from Amador, Calaveras, El Dorado, Glenn, Inyo, Mariposa, Merced, Placer, and Tuolumne Counties, but has been mined recently in El Dorado, Inyo, Tuolumne, and Placer Counties only.[2] The only operating slate prop-

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[1] Roofing slate is sold in the United States by a unit called the square, which is equivalent to 100 square feet, with a specified overlap—as a rule 3 inches.

[2] Dolbear, S. H., Economic mineral resources and production of California: California Div. Mines Bull. 130, p. 89, 1945.

Averill, C. V., King, C. R., Symons, H. H., and Davis, F. F., California mineral production for 1946: California Div. Mines Bull. 139, p. 157, 1948.

Aubury, L. E., The structural and industrial materials of California: California Min. Bur. Bull. 38, pp. 149-154, 1906.

erty in the state during 1947 was at Chili Bar, El Dorado County. The Chili Bar mine, operated by Pacific Minerals Company, has been active since about 1924.

During 1945-46 a small output of slate building veneer came from the Hodgson quarry, south of Colfax, in Placer County. From 1937-40 the following mines produced intermittently: Pacific Slate Products Corporation, Copperopolis, Calaveras County; Losh property, Placerville, El Dorado County; Mt. Whitney Slate Quarries, Lone Pine, and Red Slate quarry, Keeler, Inyo County; and Whitney Slate quarry, Hetch Hetchy, Tuolumne County. The Whitney Slate quarry and the Mt. Whitney Slate quarries produced roofing granules while most of the others produced slab slate.

The Placerville slate district has been the greatest and most consistent producer in the state and the Chili Bar mine is the oldest in that area.[3] The majority of the mines were on the north side of the American River. About 1904 a cableway was constructed to transport finished roofing slates to the south side of the river near Placerville.

At the Chili Bar mine, on the south side of the river, the Mariposa slate forms a band 2 miles wide, trending approximately N. 20° W., and dipping 85° E.[4] The slate is dark gray to black with occasional quartz stringers and rare masses of iron sulfide. The effects of surface weathering extend to a depth of about 50 feet and such weathered material is not mined. The geologic setting of almost all the Sierran slate deposits is similar. The schistosity dips steeply to the east, irrespective of the attitude of the original bedding.

Although most California slate is dark gray to black, some areas, as those in Inyo County, contain slate with colors which may range from brick red through brown to green and gray to black, depending on the content of green chlorite, brown iron oxide, or black graphite.

In world production, Belgium, U. S. S. R., France, Germany, Great Britain, and the United States are leaders. The principal domestic deposits are in Maine, Vermont, New York, Pennsylvania, Maryland, and Virginia.[5]

Utilization. Slate is a structural material which is used primarily as roofing granules and slabs, flagstone, table tops, blackboards, electrical insulation, paint, roofing paper, and lincoleum filler. In California the entire production is now consumed in granule and dust manufacture, although slab slate has been produced in the past. The small demand for slate slab in California is supplied by out-of-state sources. Roofing granules in general are discussed in the chapter on stone. Slate owes its value to its perfection of cleavage, resistance to fire, insulating qualities, and strength; although its original unit cost is high, it will generally outlive the structure in which it is used.

Prices of slate have followed very closely the general price trend of all building materials for several decades. Average national price in 1946 was $13.51 a square (the slate necessary to cover 100 sq. ft. with a specified overlap), which was up 40 percent from the 1945 price of $9.64.

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[3] Dale, T. N., and others, Slate deposits and slate industry of the United States: U. S. Geol. Survey Bull. 275, pp. 56-59, 1906.

[4] Lindgren, W., and Turner, H. W., U. S. Geol. Survey Geol. Atlas, Placerville folio (no. 3), 1894.

[5] Behre, C. H., Jr., Slate, in Industrial minerals and rocks, 2d ed., pp. 927-944, Am. Inst. Min. Met. Eng., 1949.

Mining Methods. As the operator of the Chili Bar slate mine is marketing only granules and dust, a simpler mining procedure can be employed than is required for the extraction of slate slabs. Slab removal requires great care to prevent breakage. Blasting causes shattering and therefore has to be kept at a minimum in slab production. The slabs must later be hand-split to the desired thickness and trimmed to size. Even when slabs are desired, about three-quarters of the material mined is not usable as such.

At Chili Bar, development, which is entirely underground, consists of several drifts, each about 20 feet wide by 20 feet high, and one shrinkage stope. Areas with abundant quartz stringers are avoided, as excessive quartz is undesired in the finished product; moreover, quartz-rich rock in this area tends to cave easily. After blasting, all material is hauled to the mill, which is near the mine portal, and is ground and screened to granule size. Fines are ground to a minus 280 mesh dust and bagged for use as asphalt and linoleum filler.

STONE

By Mort D. Turner

The term "stone," in commercial usage, is generally applied to material that has been quarried from larger masses of rock. The material in place, before it is broken or cut, is known as "rock." Stone is marketed in two principal classifications: (1) Dimension stone which is produced in specified shapes, and (2) Crushed stone in which the shape is not specified.

Stone production is among the oldest and largest of the mineral industries of California. Previous to the early nineteen-hundreds the production of dimension stone in the state greatly exceeded that of crushed stone; but the dimension stone output has dwindled in the last 40 years and crushed stone production has increased many fold. During 1948, the production of dimension stone had fallen so far behind that of crushed stone that it amounted to about 0.1 percent of the total tonnage of stone produced in California. The paving and construction industries, which were previously the greatest dimension-stone outlets, now use concrete in which crushed stone is a constituent.

California ranked fourth among the states in stone production[1] in 1948, when 11,936,240 tons valued at $13,155,454 were produced. Crushed stone ranked in value only behind petroleum products, cement, and sand and gravel among California's mineral commodities.

The great increase in construction since World War II has caused a corresponding increase in the production of stone. Crushed or dimension stone is being actively produced in over half of California's counties and has been produced in most of the others in the past.

Although many operations are large and continuous, and serve large areas, others are relatively small and operate intermittently to supply local needs. Some large operations have been active only during the life of a single project, such as the construction of a dam or bridge.

Industrial Classification and Uses. The stone industry recognizes the following stone classifications based on composition and texture:

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[1] Josephson, G. W., and Jensen, N. C., Stone: Minerals Yearbook 1947, pp. 1089-1121, 1949.

(1) granite, (2) basalt and related rocks, (3) marble, (4) limestone, (5) sandstone, (6) slate, and (7) miscellaneous stone. Slate is treated in a separate chapter of this bulletin.

On the basis of use, the broad classification "crushed or broken stone" is subdivided into (1) crushed stone (aggregate material), (2) riprap, (3) furnace flux, (4) refractory stone, (5) agricultural stone, and (6) stone used for miscellaneous purposes. Crushed stone is primarily used for cement aggregate and road metal. Riprap consists of large masses of broken stone, and is used in the protection of fills and in the construction of breakwaters. Furnace flux, used in the refining of iron ore, is entirely limestone and marble. Refractory stone is a very friable clayey sandstone used in the manufacturing of refractory brick and as foundry sand and ladle lining. Agricultural stone is calcareous material such as limestone, marl, and sea shells, which is added to soil. Stone is also used for poultry grit, stone sand, and roofing granules; and in concrete blocks. It also has various chemical and industrial uses.

Dimension stone is subdivided by uses into (1) building stone, (2) monumental stone, (3) paving blocks, (4) curbing, and (5) flagging. Building stone is marketed as (1) rough construction stone, which is rough-faced and of non-uniform shapes; (2) rubble consisting of irregular fragments having only one good face; and (3) cut stone, slabs, and mill blocks, which are cut to definite shapes and sizes with smooth, or even polished, faces.

Granite. In the stone industry most coarse-grained igneous rocks are called granite, regardless of their mineral composition. Granite is composed primarily of the feldspar minerals (aluminum silicates of potassium, sodium, or calcium) and ferro-magnesian minerals (dark minerals which contain iron and magnesium). Quartz is also a common constituent. Unweathered granites are generally hard, strong, tough, and resistant to abrasion and impact and are well suited to use as riprap and aggregate material. Granite riprap is quarried where large blocks can be obtained and inexpensively transported to areas of consumption. Granites which are durable, decorative, and which can take a high polish are used as building and monument stones.

Granite rocks are exposed over wide areas of California, particularly in the Sierra Nevada, the Mojave Desert, and the Peninsular Ranges; but dimension stone has been quarried at relatively few localities. Numerous granite deposits, however, are being worked for crushed stone.

Most of the active granite dimension-stone quarries in California are now producing monument stone. During 1948, 5,330 tons of dimension granite with a value of $285,214 were produced in California. This production was obtained largely in San Diego and Fresno Counties. In San Diego County [2] "black granite" is quarried from gabbro exposures near Pala, Escondido, and San Marcos. Gray granite is quarried in an area east of Lakeside. In Fresno County [3] the only producer is at Academy.

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[2] Tucker, W. B., and Reed, C. H., Mineral resources of San Diego County: California Div. Mines Rept. 35, pp. 42-44, 1939.

Aubury, L. E., The structural and industrial materials of California: California Min. Bur. Bull. 38, pp. 52-53, 1906.

[3] Laizure, C. McK, San Francisco field division—Fresno County: California Div. Mines and Mining Rept. 25, pp. 314-316, 1929.

FIGURE 1. Chart showing amount and value of stone produced in California, 1900-48, and in the United States, 1900-47.

The Raymond district, Madera County,[4] has been the principal source of granite building stone in California. The several quarries in the district furnished stone for many of the buildings in the San Francisco area and, during 1925, the production was valued at more than $1,300,000.

The oldest granite building-stone quarries in California are those at Folsom, Sacramento County, which were opened in 1856[5] to supply San Francisco's construction needs. In 1864, quarries were opened in the Penryn district, Placer County, and have been active to the present time. Granite is also obtained from quarries near Susanville, Lassen County; Rocklin, Placer County; Perris, Riverside County; and Victorville, San Bernardino County.

Granite as a building stone has been used extensively in California, especially in large business and public buildings. It has also been used in the construction of sea walls, breakwaters, bridges, and dams. In recent years concrete has largely replaced granite in all of these uses.

Granite used as paving blocks and curb stones has generally been obtained from the same sources as granite building stone. Both paving blocks and curb stones have been produced in large quantity in the past and both are still in wide service. No paving blocks and only a very small tonnage of curbing stones have been marketed in recent years. Durable stone curbs have, in general, proved more serviceable than concrete and can be re-used indefinitely as streets are widened or changed. Much of the curbing of San Francisco is granite.

In California granite is produced entirely from quarries. These are usually on hillsides where exposures are good and the problem of waste disposal simple, although some quarries such as those in the Rocklin granite district of Placer County are in relatively flat country. Granite is usually split by drilling a series of holes along the plane of desired break and then wedging or blasting the block free. The blocks of granite are transported to yards or buildings where they are sawed, turned, or trimmed to desired sizes and shapes. Polishing or carving is also commonly done in the stone yard. Dimension granite is sold in standard shapes or is cut to specifications.

A total of 1,562,010 tons of crushed and broken granite valued at $1,466,917 was produced in California during 1948. About half of the yearly output is used as aggregate material in concrete and road metal. The remainder is used mostly as railroad ballast, riprap, and for miscellaneous purposes.

Granite suitable for aggregate is widespread throughout the state. To produce the best aggregate, granite should be relatively unweathered; but close joining and fracturing facilitate quarrying and crushing. The necessary properties of aggregate material are discussed more fully in the sand and gravel chapter in this bulletin.

In construction, crushed rock is almost always used with cement as a binder, but in paving the binder is commonly a bituminous material such as asphalt. Much road metal is used without any binder other than clay.

Granite aggregate and railroad ballast are quarried extensively in Plumas, San Benito, San Bernardino, San Diego, and San Mateo Coun-

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[4] Aubury, L. E., op. cit., pp. 28-34.

[5] Hawes, G. W., and others, Report on the building stones of the United States and statistics of the quarry industry for 1880, pp. 96-97, 352, 353, Census Office, 1884.

ties. Unusually large operations are near Logan, San Benito County. Granite riprap is obtained from quarries near Eureka, Humboldt County; Bly Junction, Riverside County; Logan, San Benito County; and San Diego and San Mateo Counties. Production of granite riprap in California in 1947 amounted to 134,320 tons, valued at $135,304.

For most uses, crushed and broken stone must be produced cheaply and in large quantities. The costs of mining, crushing, and marketing are, therefore, fully as important as the quality of the rock. The deposits must be large enough to insure reserves and be located where the haul to the mill is short and cheap, preferably downhill. Likewise, the haul to the point of usage must be as short as possible.

Basalt and Related Rocks. Commercial basalts may be any of the dense, fine-grained, dark-gray or black volcanic rocks. They are composed primarily of feldspar and ferro-magnesian minerals. Basalt and related rocks are extensively exposed throughout much of the central Coast Ranges of California. These rocks ordinarily occur as flows in the Jurassic Franciscan formation and in various Tertiary formations, such as the Sonoma volcanics exposed north of San Francisco Bay.

California furnishes about 6.4 percent of the total domestic production of basalt and related stone. During 1948 the production of crushed and broken basalt in the state was 1,312,990 tons valued at $1,379,099, of which about 70 percent was used as concrete aggregate and road metal. The remainder was railroad ballast and riprap.

In the past much of the basalt quarried in California was used as paving blocks and building stone. In certain industrial and warehouse areas, and on very steep hills, basalt paving blocks are still preferred because of their resistance to shock and abrasion. They are also locally used between streetcar tracks because they can be taken out and easily replaced during repair work. The low cost and smoothness of concrete and macadam paving have nearly eliminated basalt as a paving material, however.

Unweathered basalt is an unusually tough and hard rock and crushes into equidimensional fragments. It may, however, contain minerals which will react with water and cement in concrete and result in loss of strength, formation of stresses, and partial disintegration.[6] Such minerals include gypsum, zeolites, pyrite, opal, and chalcedony.

Basalt is quarried mainly in the San Francisco region. Most of the production comes from Napa County, where the largest operation is that of the Basalt Rock Company a few miles south of Napa. In the vicinity of Petaluma and Santa Rosa, Sonoma County, several other quarries are active, and it was there in 1864, that the state's first basalt dimension stone was obtained.[7] Large quantities of basalt are also obtained from the Upton quarry in Contra Costa County and from the Stanford quarry in Santa Clara County. A number of inactive deposits are located in the Cordelia region of Solano County.

Limestone. In California, more limestone is produced than any other type of stone. It is consumed principally in the manufacture of portland cement, but nearly a million tons of crushed limestone are used yearly for aggregate, industrial, and agricultural purposes. In addition,

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[6] Rhoades, R., and Mielenz, R. C., Petrographic and mineralogic characteristics of aggregates, symposium on mineral aggregates: Am. Soc. Testing Materials Special Tech. Pub. 83, pp. 39-47, 1948.

[7] Hawes, G. W., op. cit., pp. 96-97.

about 200,000 tons are sold as lime after calcining and more than 1000 tons are sold annually as dimension stone. A more complete discussion of the limestone used for cement and lime will be found in separate chapters in this bulletin.

Limestone is a fine-grained sedimentary rock composed largely or entirely of the mineral calcite ($CaCO_3$). Dolomite, a rock composed essentially of the mineral dolomite [$CaMg(CO_3)_2$], is also commercially classed as limestone when sold as crushed rock. In contrast to basalt and granite, limestone is soft enough to be easily scratched with a knife and is readily dissolved by acid solutions. The color of pure limestone is white, but impurities such as iron oxide or carbonaceous matter may impart color. Nearly all limestone contains at least a small amount of clay. A high proportion of clay lessens the strength of the limestone and commonly makes it useless as road metal, railroad ballast, or dimension stone.

Most limestones are marine in origin and have formed from the accumulation of shells and coral, or by the chemical precipitation of calcite. Limestones also form in fresh water, but these deposits are usually limited in extent. Travertine ($CaCO_3$ deposited from solution in ground or surface waters) is marketed either as marble or as limestone, depending upon the use to which it is put.

Most commercial limestone in the state occurs in Paleozoic and Mesozoic formations. The Jurassic Franciscan formation in the Coast Ranges and various pre-Jurassic formations of the Mojave Desert and Sierran foothill regions have been the principal sources.

Very extensive, thick beds of Devonian, Permian, and Triassic limestones occur in Shasta County; but these have not been extensively exploited because they are too distant from the main areas of consumption.

The dimension limestone produced in California in 1948 was entirely used as rubble and building stone. Rough-construction limestone was obtained from El Dorado County near Auburn, and rubble from Diamond Springs in El Dorado County, Santa Cruz in Santa Cruz County, and Sonora in Tuolumne County.

In 1948 eleven counties yielded crushed and broken limestone for uses other than the manufacture of lime and cement. The largest output was obtained from San Bernardino and San Mateo Counties.

About one-third of the crushed limestone produced in California is used as concrete aggregate and road metal; the remainder is used for industrial and agricultural purposes. The principal source of limestone aggregate is from the quarries in Jurassic Franciscan limestone at Rockaway Beach, San Mateo County.[8] Other significant operations for aggregate are elsewhere in San Mateo County, in El Dorado County, at Permanente in Santa Clara County, and at Sonora in Tuolumne County. Some limestone is quarried for riprap in Los Angeles County.

Each year about 100,000 tons of the limestone produced in California is used as furnace flux in the refining of iron ores.[9] The flux removes alumina and silica from the ore by the formation of a calcium-magnesium-aluminum silicate slag which floats on the surface of the molten iron and

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[8] Logan, C. A., Limestone in California: California Jour. Mines and Geology, vol. 43, pp. 307-309, 1947.

[9] Bowles, O., and Jensen, N. C., Industrial uses of limestone and dolomite: California Jour. Mines and Geology, vol. 45, pp. 319-334, 1949.

is removed. Limestones low in silica and alumina and very low in sulfur and phosphorus make the best furnace fluxes.

Calcium in the form of the carbonate ($CaCO_3$), quicklime (CaO), or hydrated lime [$Ca(OH)_2$] is used in many parts of the state for agricultural purposes. When it is added to the soil as the carbonate, it is called agricultural limestone. A large part of the agricultural limestone used in California is in the form of shells, dredged from San Francisco Bay; or marl, a natural clay-calcium carbonate mixture. The remainder is finely ground limestone rock. These calcium compounds are used primarily to furnish calcium as a plant food, loosen heavy soil, and neutralize acid soil.[10]

Finely ground limestone is used as a filler in paint and asphalt. Ground limestone is also used as an ingredient in the manufacture of glass. Beet-sugar factories purchase large quantities of coarsely crushed limestone of high purity for the production of lime and carbon dioxide to be used in beet-sugar refining. Such limestone is known commercially as sugar rock. Limestone is also converted into lime for use in the manufacture of sulfite paper.

During 1948, quarries at Hinkley and Victorville in San Bernardino County, and Diamond Springs and Shingle Springs in El Dorado County, produced furnace flux. Limestone from deposits in El Dorado, Inyo, Monterey, San Bernardino, Santa Cruz, Tuolumne, and Ventura Counties is marketed for agricultural stone, poultry grit, sugar rock, roofing granules, paint filler, whiting, refractory magnesia, and chemicals. Some of these deposits contain coarsely crystalline limestone (marble) but are included here because they are statistically listed as limestone.

Most limestone is mined by open-pit methods. The face is usually blasted down and the broken stone loaded by power-shovel into trucks for transportation to the crusher. Conveyor belts or rail transportation are frequently used between truck and plant. At Sonora and at Shingle Springs, in the Mother Lode Belt, limestone is mined by underground methods.

Marble. Marble, to the petrologist, is a granular crystalline limestone. Commercial marble, however, is generally defined as any calcareous rock that can take a polish and the term will have this meaning in the following discussion.

Some marbles are almost entirely composed of carbonate minerals; others contain such impurities as silica and silicate minerals, iron oxide and iron sulfide minerals, and organic matter. Marble commonly is white, but the iron oxides impart colors of tan, red, or brown; organic matter will cause a gray to black color. Most serpentine-rich marble is greenish. The presence of silicate minerals increases the hardness and makes mining and cutting or crushing more difficult.

Marble has been produced from deposits of the pre-Franciscan Gabilan limestone of the central Coast Ranges; from the Paleozoic Calaveras formation in the Sierra Nevada; and from Paleozoic rocks in Inyo, San Bernardino, and Riverside Counties.

Only a small output of dimension marble has been recorded for the past several years in California; but previous to the depression of 1932 it was produced in relatively large amounts. In 1904, one of the years

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[10] Logan, C. A., op. cit., pp. 181-185.

of great marble production in California, quarries at the following localities were active: near Plymouth, Amador County; north of Keeler, Inyo County; Crestmore, Riverside County; Victorville and Colton, San Bernardino County; and Columbia, Tuolumne County.[11] Other operations have been active at various times, notably in central San Luis Obispo County, and at Cement, Solano County.

During 1948 all of the marble dimension stone used in the state was shipped in from other areas; most of it was from Georgia, Tennessee, Vermont, and Italy. It is used in making markers and memorials and in interior and exterior finishing of buildings.

Crushed marble is used in the same way, and for the same purposes, as crushed limestone. Large amounts are used for flux, agricultural stone, and roofing granules, and colored marbles are used for the manufacture of cast stone and terrazzo.

Crushed marble, classified as limestone, is currently being produced in El Dorado and Tuolumne Counties; at Natividad, Monterey County; northeast of Bishop in Inyo County; and at Victorville, San Bernardino County. The only marble production, listed as such in the state, is at Sonora in Tuolumne County, where terrazzo material is quarried.

Sandstone. Sandstone is a sedimentary rock composed of cemented and compacted sand grains. The most common cements are calcite, silica, iron oxide, and clay. The sand grains are ordinarily quartz and feldspar. Quartz predominates in many sandstones and in some localities forms almost all of the grains.

The sandstone of the Jurassic Franciscan formation, which is widespread in the central Coast Ranges, characteristically contains basic feldspar and small rock fragments, and is known as graywacke. Much of the extensive Cretaceous and Tertiary sandstone of the Coast Ranges contains the more acid feldspars, and is known as arkose.

The most extensive and uniform deposits of sandstone are those laid down in shallow seas. Much of the sedimentary rock deposited in California since Upper Jurassic time has been sandstone. Most of the state's sandstone is exposed in the Coast Ranges of northern and central California and the Transverse and Peninsular Ranges of southern California.

During 1948, only 6,990 tons of dimension sandstone, valued at $49,015, were produced in California, but the 1903 output of an undisclosed tonnage was valued at $583,309. In 1948, the crushed and broken sandstone production in California reached 1,522,120 tons valued at $1,403,923. This was 21.5 percent of the total United States production.

Probably the earliest production of dimension sandstone in California was from Angel Island in San Francisco Bay in 1865 or earlier.[12] Quarries in Jurassic Franciscan sandstone furnished building stone for construction in San Francisco and partially displaced sandstone imported from British Columbia and elsewhere.

The most productive operations in the state have removed dimension stone from Upper Cretaceous sandstone in Colusa County. These deposits were worked steadily from 1901-19 and intermittently and on a smaller scale until 1942. They are now idle. Three quarries at the town of Sites in northern Colusa County furnished a large part of the building stone used in San Francisco, including that used in the construction of the

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[11] Aubury, L. E., op. cit., pp. 95-112.
[12] Hawes, G. W., op. cit., p. 352.

Ferry Building and the St. Francis Hotel. The sandstone layers that were worked ranged from 18 inches to 45 feet thick, and were interbedded with shale.

Another important source of sandstone building stone in California was the Goodrich quarry 9 miles south of San Jose in Santa Clara County. The producers mined steeply dipping buff-colored sandstone beds up to 10 feet thick. The rock was quarried by hand and trammed to a stone mill and cutting yard where it was cut to size and shape by gang saws. The main buildings of Stanford University, as well as many other buildings in the San Francisco Bay region, were constructed of this sandstone.

''Sespe brownstone'' from Sespe Canyon, Ventura County, has been quarried extensively for use in construction throughout California. This sandstone has an even fracture and was easily quarried. Some Sespe-type sandstone is now being quarried in Santa Barbara County. Large amounts of dimension sandstone were produced in Los Angeles, San Luis Obispo, and Santa Barbara Counties. Quarries at Pasadena, Los Angeles County, Carmel, Monterey County, and in Napa County are still active.

Crushed and broken sandstone for use as concrete aggregate, road metal, ballast, riprap, and refractory sand now forms the bulk of the sandstone production of the state. The Jurassic Franciscan formation in the San Francisco Bay area is the source for the largest part of this output. Alameda, Marin, and San Mateo Counties, in that order, have the greatest sandstone productions. In Alameda County, sandstone is obtained from a series of quarries along the west side of the Berkeley Hills, from North Oakland to Niles. This is used for fill, riprap, and concrete aggregate. In Marin County, most of the quarries are near the San Francisco Bay shore, as at Greenbrae Station and McNear's Point, where the crushed and broken rock may be transported by barge if desired. The largest riprap production in California comes from these two Marin County quarries.

Relatively small but commercially important amounts of refractory sandstone, used to produce refractory brick, foundry sand, and ladle lining, are mined at Tesla, Alameda County, and El Toro, Orange County. The rock at both localities is an extremely friable, clayey sandstone. At El Toro the sandstone is a part of the Paleocene Silverado formation; [13] at Tesla it is in the Eocene Tesla formation.[14]

During 1946, an estimated 4,000 tons of refractory sandstone and quartzite were produced in the state.

Except for the Tesla refractory sandstone, all the crushed and broken sandstone in California is mined by open pit. At Tesla the steeply dipping sand beds are mined by underground workings.

Miscellaneous Stone. Miscellaneous stone includes such diverse rock types as certain light-colored volcanics, schist, serpentine, and river boulders. During the last several years, California has been the leading state in the production of miscellaneous types of stone. During 1948 the state yielded 6,743,480 tons of miscellaneous stone valued at more than six and one-half million dollars. This represented about 40 percent of the total national production. Most of the miscellaneous stone produced in California is obtained from alluvial deposits.

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[13] Stauffer, C. R., High-alumina clays of the Santa Ana Mountain region, California: U. S. Geol. Survey Strategic Minerals Investigations, Prelim. Map 3-197, 1945.

[14] Huey, A. S., Geology of the Tesla quadrangle, California: California Div. Mines Bull. 140, pp. 33-38, 1948.

Stone crushed from gravel and boulders is usually produced along with uncrushed sand and gravel at the same operation. Most crushed stone from gravel and boulders is used in concrete, road metal, and railroad ballast. As in basalt, reactive minerals such as opal, zeolite, or pyrite, are commonly present in alluvial material.

Crushed gravel and boulders are produced from nearly every part of the state where there are sand and gravel operations, but an especially large output of the crushed material is obtained in the San Fernando and Azusa-Arcadia areas of Los Angeles County, and in the Livermore Valley and Niles areas of Alameda County. Another source of raw material is dredge tailings. Two plants in Butte County crush dredge tailings from the Feather River valley near Oroville and from Butte Creek near Chico.

Much of the light-colored volcanic rock produced in California is from the Tertiary formations of the San Francisco Bay area. In Sonoma County several quarries are currently producing flagstone and crushed stone for concrete aggregate. Tertiary intrusive andesite and dacite plugs in San Luis Obispo County, from San Luis Obispo to Morro Bay, have furnished a large tonnage of both dimension and broken stone.

The rock serpentine is produced by hydrothermal alteration of peridotite, dunite, and related ultrabasic rocks. It is composed largely of the green mineral serpentine but contains minor amounts of amphibole, pyroxene, calcite, and olivine. Serpentine has been used in California as a decorative building stone and in the manufacture of superphosphate fertilizer.

Schist, a metamorphosed sedimentary or igneous rock, with a pronounced foliation, is used as flagging. Crushed schist is also used as roofing granules.

Roofing Granules.[15] The manufacture of roofing granules is one of the principal crushed-stone industries in California. Granules are applied to roofing manufactured in rolls or shingles, or to roofing that is built up when it is installed. Granules reflect light, decrease heat absorption, retard the weathering of the asphalt-impregnated felt base, and the deterioration of asphalt by ultra violet rays.

Among the many localities from which granules for roofing are being produced, are the slate mine at Chili Bar in Placer County, where dark-gray to black granules are being produced; the large quarry in metamorphosed volcanic rock a few miles southeast of Corona, Riverside County; the limestone deposits at Shingle Springs in El Dorado County, and near Bishop in Inyo County; and the limestone deposits at Natividad in Monterey County. For several years green granules were produced from greenstone by underground workings at Angels Camp, Calaveras County.

Granules used on rolls or shingles are about 14 mesh. Those used in built-up roofing are coarser (usually about a quarter of an inch in diameter). These are spread over the surface of a coating of hot asphalt. Built-up roofing is used on slopes of about 16 degrees (30 percent) or less.

The production of granules with uniform and permanent colors has been a problem. Although naturally colored rock is generally satisfactory,

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[15] Ingram, S. H., Roofing granules in the southwest: California Jour. Mines and Geology, vol. 45, pp. 455-458, 1949.

uniformity of color is difficult to maintain in producing in the natural material.

Within recent years artificial coloring on neutral-colored granules has been widely used. The principal material of this type is a coating of low-fusion, colored ceramic glaze which is permanent and becomes an integral part of the granule. Another method yields artificial granules by fusing and crushing red- or brown-burning clay. These have a permanent red or brown color.

At one time the plant at Chili Bar, Placer County, produced slate granules coated with aluminum paint which gave a very high reflectivity.

The demand for white granules in the quarter-inch range for built-up roofs has been partially satisfied by the use of white, coarsely crystalline marble, although gray granules colored white are also being marketed. A trend is developing toward large-sized colored granules.

The granules to be usable must be resistant to abrasion during transportation, but must be easily crushable without a high loss in fines. Weather resistance and ability to bond well with asphalt are important, and the color must be uniform if the granule is to be used with its natural color. Any iron oxide is detrimental in white granules. Where the granule is to be artificially colored it must, in addition, have an even texture throughout the deposit because color absorption depends on this factor. Contaminants that affect the ceramic glaze color must be avoided and a neutral-gray color is desirable to cut consumption of pigment.

Crushing is usually done at the quarry to save freight on the material that will eventually be lost as fines. Great care must be taken that the final product is entirely free of dust and other fines which prevent the bonding of asphalt to the granule.

At Chili Bar a plant at the mine crushes, screens, and oils the slate to produce finished granules. The quarry near Corona furnishes material for one of the largest and newest roofing-granule plants in the state, that of the Minnesota Mining and Manufacturing Company. Large-sized, colored granules are now being produced from a plant at Puente, Los Angeles County.

Although no figures are available on total roofing-granule production in California because roofing granules are included in the statistics for stone, it is known that the quantity has been rising in recent years.

STRONTIUM MINERALS

By William E. Ver Planck, Jr.

Although California's strontium reserves are among the largest in the United States and compare favorably in grade with imported materials, distance from markets and high transportation costs have made them uneconomical to mine in normal times. Strontium minerals were mined from 1916-18 and again from 1939-46 when imports were restricted and the demand was unusually great; but since 1946 no strontium has been produced in California. The total production of 15,014 tons has come from three localities: the Fish Creek Mountain deposit in Imperial and San Diego Counties; deposits on the south slope of the Cady Mountains, San Bernardino County; and deposits in the Mud (Strontianite) Hills

10 miles northeast of Barstow. Additional reserves exist in the northern foothills of the Avawatz Mountains.

Mineralogy and Geologic Occurrence. Celestite ($SrSO_4$) and strontianite ($SrCO_3$) are the only strontium-bearing minerals that have been mined in California. Celestite, which is much the more common, occurs as a chemical precipitate which may or may not be associated with saline minerals. Much more rarely celestite occurs in hydrothermal veins or as disseminations in and replacements of sedimentary rocks, especially limestone.

Deposits of strontianite are rare, not only in California but throughout the world. In California strontianite deposits of possible commercial value occur as nodules and concretions in shaly tuff.

Localities. In the foothills of the Cady Mountains, San Bernardino County, about 3 miles northwest of Argos, a celestite zone outcrops for 4000 feet.[1] Here celestite beds, up to 5½ feet thick, are interbedded with shaly tuffs and tuffaceous clays that form part of a thick series of volcanics. The average thickness of celestite rock is 50 feet. The celestite is a finely crystalline light-colored buff to greenish rock, most of which contains some chalcedony. In the eastern end of the zone jasper and chalcedony have replaced masses of celestite. Reserves are estimated at 1,140,000 tons.[2]

The Fish Creek Mountain deposit, Imperial and San Diego Counties,[3] is on an outlying hill north of the gypsum deposit of the United States Gypsum Company. The hill is capped by massive white celestite in nearly horizontal beds up to 10 feet thick. A 3-foot thickness of interbedded celestite and gypsum lies between the celestite and the underlying gypsum beds that comprise the greater part of the hill. Reserves of celestite are estimated to be 10,000 tons.

In the northern foothills of the Avawatz Mountains, San Bernardino County, celestite is in Tertiary lake beds which are involved in the complex structures of the Garlock and related faults.[4] Celestite occurs interbedded with gypsum, but is confined to the western portion of the gypsiferous belt described in the section on gypsum in this volume.

Individual celestite beds are as much as 3 feet thick and 1000 feet long. They are composed of relatively pure celestite near the center, but grade at the top and bottom into gypsiferous celestite. Along the strike they thin out and are represented by nodules of celestite in gypsum. Reserves are estimated at 14,000 tons.

Ten miles northeast of Barstow strontianite deposits occur in clays of the middle member of the Barstow formation.[5] Individual bodies, few of which contain more than 1 cubic yard of material, are found through a thickness of several hundred feet of the clays in a belt 2 miles long. Strontianite has formed as nodular masses that are elongate parallel to the bedding, and as concretions that lie across the bedding. Some of the strontianite masses are dark brown, resinous and fibrous, others are composed of dull, gray, fine-grained material that resembles limestone. Both varieties contain up to 10 percent calcium carbonate.

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[1] Moore, B. N., Some strontium deposits of southeastern California and western Arizona: Am. Inst. Min. Met. Eng. Trans., vol. 115, pp. 357-362, 1935.

[2] Durrell, Cordell, Strontium deposits of southern California (abstract): Geol. Soc. America Bull., vol. 58, p. 1250, 1947.

[3] Moore, B. N., op. cit., pp. 368, 369.

[4] Moore, B. N., op. cit., pp. 365-368.

[5] Knopf, Adolph, Strontianite deposits near Barstow, California: U. S. Geol. Survey Bull. 660, pp. 257-270, 1918.

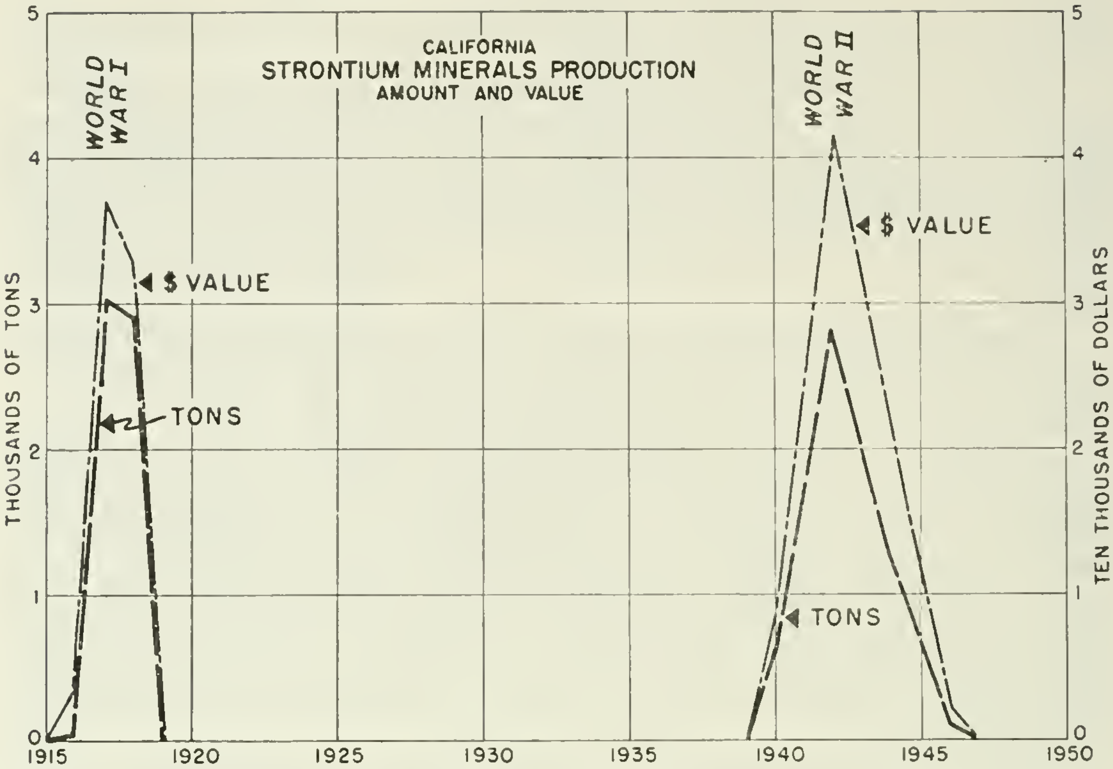

FIGURE 1. Chart showing amount and value of strontium minerals produced in California, 1915-19, 1939-47. Curve for the years 1941-46 represents 2-year averages.

Celestite nodules occur in clay on the south edge of Bristol Lake and near Owl Hole Spring, San Bernardino County. A vein of celestite was found in the Butts quicksilver mines, San Benito County. Crystals of both celestite and strontianite occur in the borate mines near Barstow and Daggett.

Uses. The greatest use of strontium compounds is in red flares.

Typical analysis of red railroad fusees *

	Percent
Strontium nitrate	71.1
Potassium perchlorate	13.1
Sulfur	11.1
Sawdust	4.2
Charcoal	0.5

* Harness, C. L., Strontium minerals: U. S. Bur. Mines Inf. Circ. 7200, p. 5, 1942.

Strontium compounds are an ingredient of the red tracer bullets used in enormous quantities in times of war. Low-grade celestite is a substitute for barite in oil-well drilling mud. Minor uses are as medicinal salts, for purifying caustic soda used in rayon manufacture, as a substitute for barite in fillers and paints, and in lubricants.

Markets. Most of the strontium consumed in the United States in normal times is imported from England in the form of celestite. It is brought to East Coast ports at ballast rates. For use as oil-well drilling mud celestite has been able to compete with the more desirable barite mud because the use of the latter was patented and users paid a royalty of $17 a ton. Celestite lost this advantage when the patent expired in 1943.[6]

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[6] Harness, C. L., Strontium minerals: Minerals Yearbook 1946, p. 1296, 1948.

The price of crude celestite, according to the Minerals Yearbook was $28 to $30 a short ton at Philadelphia in 1946. In 1949 the price of crude celestite had declined to $19 a ton, 90 percent grade, f.o.b. cars, California. Strontianite in 1949 sold for $55 a ton for material of 84-86 percent grade in car lots.[7]

Treatment. At the Foote Mineral Company plant in Philadelphia [8] crude celestite is crushed, dried, ground to 90 percent minus 325 mesh, and treated with sodium carbonate in reaction tanks. An impure precipitate of strontium carbonate forms, which is treated to remove barium and calcium compounds. Strontium chloride, strontium hydroxide, and other strontium compounds are made from the strontium carbonate.

History of Production. Although occurrences of strontium minerals in California have been known for many years, most of the large deposits were found during the early years of World War I. Perhaps the earliest discovery of a large deposit was that in the Avawatz Mountains, during or prior to 1911. The Barstow deposits were discovered in 1915 by Henry Hart and T. G. Nicklin who were prospecting for borax.[9] The first description of the Cady Mountains deposit is that of Mallery [10] in 1916, who stated that the nature of deposit had "only recently" been realized.

Before 1914 the principal strontium compound used in the United States was strontium nitrate made in Germany. The German factories first used strontianite mined in Germany, and later used celestite imported from England. The abrupt curtailment of this source of supply encouraged the mining of California strontium minerals and the establishment of processing plants, both in California and in the east. From 1916-18 the deposits near Barstow, in the Cady Mountains, and in the Fish Creek Mountains were worked. After 1918 celestite from England was available at low cost, and the California mines were closed.

During World War II the use of strontium compounds in tracer bullets and to a lesser extent in military flares increased the demand enormously. The California mines were reopened, and a very small production in 1939 increased to about 20 percent of the national consumption in 1943. Imports during World War II came from England, Spain, and Mexico.

Two companies contributed most of the California total. These were the Pan Chemical Company which operated the Fish Creek Mountains deposit and the Rowe-Buehler Mining Company which operated a mine in the Cady Mountains. The DuPont Company mined a smaller tonnage from their Cady Mountains deposit, and some celestite was produced by Edgeo, Inc., from a deposit in San Diego County. Some strontianite was mined by the Strontium Carbonate Mines, Strontianite Hills, near Barstow, during 1939, 1940, and 1941.

SULFUR

By James W. Vernon

Modest tonnages of sulfur have been intermittently produced from sources in California, chiefly from deposits of elemental sulfur in Inyo

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[7] Eng. and Min. Jour., Metal and Mineral Markets, vol. 20, New York, McGraw-Hill Publishing Company, Inc., 1949.

[8] Strontium chemicals: Chem. Met. Eng., vol. 53, no. 1, pp. 152-155, January 1946.

[9] Knopf, Adolph, op. cit., p. 257.

[10] Mallery, Willard, A discovery of celestite: Min. Sci. Press, vol. 113, p. 952, 1916.

County. The state's total production exceeds 52,000 long tons valued at more than $850,000. A peak of nearly 10,000 long tons was reached in 1941; only 698 long tons of sulfur ore were produced in 1947. Much of the sulfur used in the manufacture of sulfuric acid does not appear in statistics as elemental sulfur. Such sulfur sources include pyrite (FeS_2) mined in Shasta County and used mostly in sulfuric acid production (see section on pyrite); other sulfide minerals from the smelting of which sulfuric acid is obtained as a by-product; and hydrogen sulfide gas evolved during petroleum refining. Most of the elemental sulfur consumed in California, however, is from out-of-state sources.

Localities and Geologic Occurrence. Native sulfur has been noted in several California counties, including Alpine, Colusa, Imperial, Inyo, Kern, Lake, Sonoma, Tehama, and Ventura. Recent commercial production has come from Imperial, Alpine, and Inyo Counties.[1]

The first sulfur production in California was from the Sulphur Bank mine, Lake County, during the period 1865-68. Sulfur was not produced again until 1923-24, when 185 tons came from one property in Kern County. During the years 1929-31 small amounts were produced at Wilbur Springs, Colusa County. Since 1932 most of California's sulfur production has come from Inyo County, supplemented by small amounts from Imperial and Alpine Counties.

California's largest known sulfur deposits, located on the western slope of the Last Chance Range in Inyo County, are in a series of limestone breccias, conglomerates, rubbly sandstone, and volcanics of Tertiary age. Here, leaching of gypsum to form sulfur was accompanied by the deposition of additional sulfur by solfataric action.[2] Lynton in 1938 conservatively estimated the ore-in-sight in these deposits to be 253,000 tons containing 40.3 percent sulfur. Total reserves were believed to be approximately 2,500,000 tons of sulfur. Both surface and underground methods have been employed in mining Inyo County sulfur. Concentration of the sulfur ore at or near the deposits has been prevented by lack of water. Imperial County sulfur ore is essentially impure gypsum containing 3 to 7 percent sulfur. At the Leviathan mine, Alpine County, sulfur minerals and native sulfur are associated with copper ore.

Most of the minor occurrences of sulfur in California are the result of solfataric action in the vicinity of recent volcanism, or are associated with cinnabar in California's numerous quicksilver deposits. The Sulphur Bank deposit, Lake County, was originally mined for sulfur, but since 1868 it has been mined for quicksilver. Sulfur is also commonly associated with borax minerals, as at Searles Lake.

The large sulfur deposits of the Gulf Coast of the United States which produce three-quarters of the world's sulfur, the extensive deposits of the Mediterranean region, and the productive deposits of Inyo and Imperial Counties, California, all occur in sedimentary beds with gypsum and limestone and are associated with sulfates, carbonates, and hydrocarbons.[3]

The close association of native sulfur with gypsum indicates that at least part of the sulfur was formed from the alteration of gypsum. This

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[1] Murdoch, Joseph, and Webb, R. W., Minerals of California: California Div. Mines Bull. 135, pp. 289-290, 1948.

[2] Lynton, E. D., Sulphur deposits of Inyo County, California: California Div. Mines Rept. 34, pp. 563-589, 1938.

[3] Ladoo, R. B., Non-metallic minerals, p. 600, New York, McGraw-Hill Book Co., 1925.

alteration has been attributed to bacteria, organic matter, and reactions of limestone with H_2S generated from the gypsum. Some deposits show evidence of being sedimentary, in part. Sedimentary types are believed to be formed in any closed basin in which H_2S is generated. The decay of organisms or the reduction of dissolved calcium sulfate by carbonaceous materials generates the H_2S; subsequent oxidation of the H_2S is effected by bacteria, or by oxygen from the air.[4]

Utilization and Markets. Three-fourths of all elemental sulfur used in the United States is converted to sulfuric acid, which is used by nearly every industry. Other uses are in insecticides, paper manufacture, rubber compounding, and fertilizers.

Chemical plants in the Los Angeles area have been the chief consumers of California sulfur. Ore from the Inyo County deposits, averaging 75-80 percent sulfur, was mined and delivered to Los Angeles for $13 per ton during the period 1932-37. The price of sulfur in 1948, f.o.b. Texas mines, was $16-18 per long ton; the 1949 price was $18.[5]

SULFURIC ACID

By James W. Vernon

Plants in California which manufacture sulfuric acid utilize several sulfur-rich materials. In some plants the acid is produced from elemental sulfur which is mined in the state, or which comes from out-of-state sources. A plant in the San Francisco area uses pyrite (FeS_2) mined at a Shasta County property specifically as a sulfuric-acid raw material. Approximately 100,000 tons of pyrite are used yearly in this process.

Sulfuric acid is also obtained as a by-product of the treatment of sulfide ores at the smelter at Selby, Contra Costa County. These ores are from other western states and several foreign countries, as well as from California. Additional sulfuric acid is produced at various oil refineries in the San Francisco Bay and Los Angeles areas. The sulfur source in these operations is the hydrogen sulfide gas evolved in the refining process.

The sources of elemental sulfur and pyrite in California are discussed in separate sections of this bulletin. Statistics on the production of sulfuric acid in California, as gathered by the U. S. Bureau of Mines, are not recorded separately, but are included in the miscellaneous classification. However, enough sulfuric acid is produced in California to satisfy most of the state's demands.

Manufacturing Processes. The first step in sulfuric-acid production involves the production of sulfur dioxide. This is done in three ways: (1) by burning elemental sulfur, (2) by roasting pyrites and sulfide ores, and (3) by burning hydrogen sulfide gas. Two general types of processes are used to make sulfuric acid from the sulfur dioxide—the nitration and the contact processes. The nitration processes involve the oxidation of sulfur dioxide by oxygen and nitric acid (or higher oxides of nitrogen) in the presence of water. The final reaction products are sulfuric acid and oxides of nitrogen. In the contact processes sulfur

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[4] Lindgren, Waldemar, Mineral deposits, 3d ed., p. 424, 1928.

[5] Eng. and Min. Jour., Metal and Mineral Markets, vol. 20, New York, McGraw-Hill Publishing Co., Inc., 1949.

dioxide is oxidized to sulfur trioxide; platinum, or vanadium pentoxide is used as a catalyst. The sulfur trioxide is subsequently absorbed in concentrated sulfuric acid.[1]

Hydrogen sulfide gas used in making sulfuric acid is selectively absorbed from oil-refinery gases by liquid sodium phenolate. It is later regenerated from solution.[2]

Utilization. Sulfuric acid is used in greater volume and has more applications than any other industrial chemical. As it is used by nearly every industry, the demand for sulfuric acid is an accurate and sensitive indicator of general business conditions.

Sulfuric acid is the cheapest acid per unit of chemical activity. Its outstanding chemical characteristics are its ability to decompose most metals and other substances, to remove organic matter, and to neutralize alkalies. Among its most important industrial uses are the manufacture of fertilizers, soap, paper, storage batteries, and explosives. It is also widely used in processes of electroplating, electrodeposition, and oil refining.

Marketing. Marketing of sulfuric acid is generally restricted to areas surrounding centers of manufacture. This is necessitated by its bulk, the expense of packaging, and the high cost and danger of transporting the acid compared with like considerations in transporting sulfur, pyrites, and niter used to produce it. Prices vary widely, depending on the lot sizes and the area of production.[3]

TALC, SOAPSTONE, AND PYROPHYLLITE

By Lauren A. Wright

The commodities talc, soapstone, and pyrophyllite customarily are discussed as a group, and the U. S. Bureau of Mines combines the annual production of these materials in a single figure. The pyrophyllite occurrences of California, however, can be conveniently considered separately and are included under a separate heading of this section. In 1948 the state's combined production of talc, soapstone, and pyrophyllite was nearly 100,000 tons. In recent years talc mining has increased sharply and pyrophyllite has been mined in quantity for the first time. Soapstone, as a relatively impure variety of talc, was mined in California long before the first production of either pyrophyllite or high-quality talc. The soapstone output, however, has always been small compared with the current output of high-quality talc.

TALC AND SOAPSTONE

Mineralogy and Geology. To the mineralogist "talc" is a distinct mineral species with a composition of $H_2Mg_3(SiO_3)_4$, but in commercial usage the term commonly alludes to a mixture of minerals most of which are high-magnesium silicates. The mineral talc is usually, but not necessarily, a prominent constituent. Other common minerals in such mixtures include tremolite $[Ca_2Mg_5Si_8O_{22}(OH)_2]$, serpentine (a hydrous magnesium silicate), chlorite (an alumino-silicate of iron and magnesium),

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[1] Fairlie, A. M., Sulfuric acid manufacture, pp. 27-48, New York, Reinhold Publishing Co., 1936.

[2] Stockman, L. P., Standard Oil operating sulfur recovery unit at El Segundo: Oil and Gas Jour., vol. 35, no. 23, p. 46, 1936.

[3] Kreps, T. J., The economics of the sulfuric acid industry, pp. 1-284, Stanford Univ. Press, 1938.

anthopyllite [$(Mg,Fe)_7Si_8O_{22}(OH)_2$], olivine [$(Mg,Fe)_2SiO_4$], carbonate minerals, and quartz. The chemical compositions of many commercial talcs, therefore, do not approximate the composition of the pure mineral.[1] The industrial usage to which the material is put determines whether a particular mineral of this group is beneficial, harmless, or undesirable.

Soapstone commonly contains a higher proportion of the mineral talc than do some commercial "talcs." But the term soapstone, as ordinarily used, implies the presence of impurities that prevent the use of the material as a high-grade commercial talc. Compactness is also an implied characteristic of soapstone.

Commercial talc deposits are ordinarily alterations of dolomite, limestones, or ultrabasic rocks. Most of the talc now produced in California has altered from dolomite or limestone. The soapstone deposits are most commonly associated with bodies of serpentine or talc-actinolite schist.

Talc Deposits of Eastern California. The talc deposits in California that have formed by the alteration of dolomite or limestone are largely confined to a 200-mile belt which parallels the California-Nevada line from the Inyo Range, Inyo County, southwestward to the vicinity of Baker, San Bernardino County. Included in this belt are three contrasting talc-bearing areas which have been designated respectively as the Inyo Range, southern Death Valley-Kingston Range, and Silver Lake talc provinces.[2] Each province contains deposits which are geologically similar. Each also contains a mine which was first opened in the period 1915-19 and which has since produced more than 100,000 tons of talc.

Inyo Range Province. Most of the talc deposits of the Inyo Range province are exposed on the east and west slopes of the range itself and in an area between Darwin and Keeler near the southern end of the range. The talc in this province has formed by the hydrothermal alteration of Paleozoic dolomite and, to a lesser extent, of silica rock and granitic rock.[3] Many of these deposits contain talc of the type known to the ceramic industry as "steatite." Steatite is an unusually pure material which is composed almost wholly of the mineral talc and which can be used as an ingredient in the manufacture of high-frequency insulator bodies. Magnesium silicate minerals other than talc are uncommon in the Inyo Range deposits. Individual talc bodies in this province are characteristically pod-like or irregularly shaped. The largest known bodies, however, are more regular than the average and have lengths of more than 500 feet and maximum widths of 50 feet. In many of the deposits the alteration has apparently been guided by shears and fractures.

The Talc City mine, about 13 miles southeast of Keeler, Inyo County, has produced over 200,000 tons since 1915 when it was first worked. This is the largest output of any talc mine in California. During World War II this property was the nation's principal source of steatite which was critically needed in the manufacture of electrical equipment for the armed forces.

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[1] In this report the term "talc," unless otherwise qualified, will be used in its commercial meaning.

[2] Wright, L. A., California talcs: Min. Eng., vol. 187, no. 1, pp. 122-128, Jan. 1950.

[3] Page, B. M., Some California talcs of steatite grade: Min. and Ind. News, vol. 16, no. 1, p. 12, Jan. 1948.

The White Mountain mine, on the southeastern flank of the Inyo Range, was also an important war time steatite producer. This mine was first worked in 1935 and has been operated nearly continuously during the past 10 years. Approximately 15 other talc mines in the province have been active in the past, but none have total outputs comparable with those of the Talc City and White Mountain properties.

Southern Death Valley-Kingston Range Province. Another province that contains geologically similar talc deposits extends from the southeast portion of the Panamint Range eastward across the southern end of Death Valley to the east side of the Kingston Range. In this area all of the commercial talc has formed by the alteration of the lowermost carbonate beds in a late pre-Cambrian sedimentary series. At or near the base of the carbonate beds a diabase sill is everywhere present and is in contact with or proximate to the talc bodies. The talc, carbonate strata, and diabase are all part of the Crystal Spring formation. At several localities the talcose horizon is exposed for a distance of well over a mile, but commercial talc concentrations within it are ordinarily less continuous.

Though all talc deposits in this province have nearly the same stratigraphic position, they differ markedly in mineralogic detail. Some deposits consist almost wholly of fibrous or micaceous varieties of the mineral talc. Other deposits contain two or more types of commercial talc. These types include compact, fine-grained and thinly laminated tremolite rock; coarse-grained mixtures of tremolite, and the mineral talc; and a massive, crudely laminated variety of the mineral talc, as well as the fibrous and micaceous types.

The Western mine, immediately south of Tecopa Pass in San Bernardino County, has been the principal talc producer in the province. Since the property was first worked in 1917, it has yielded well over 150,000 tons. Most of this production has come from a single talcose zone which is more than 5000 feet long and from 20 to 90 feet wide. The zone is underlain by a diabase sill and overlain by siliceous dolomite.

Within recent years several other properties in the province have become active. These include the Excelsior mine on the west flank of the Kingston Range; the closely grouped Monarch, Pleasanton, and Ibex mines at the southern end of the Ibex Hills; the Superior and White Cap mines near Saratoga Spring at the southernmost tip of Death Valley; and the Warm Spring mine in Warm Springs Canyon in the southeastern portion of the Panamint Range. The general geologic features at all of these properties are similar to those of the Western mine and some of the deposits are being worked on a comparable scale. At the Superior and White Cap mines the commercial talc bodies lie beneath, instead of above, the diabase sill. Numerous other talc deposits in the province have been mined in the past and still others remain to be developed. At least three are scheduled to be worked for the first time in 1950 or 1951.

Silver Lake Province. The southernmost province in the eastern California talc-bearing belt is in the vicinity of Silver Lake, San Bernardino County. Three properties are currently active in this area. The largest of these operations, the Silver Lake mine, is about 10 miles north-northwest of Baker. It has been operated since 1918, and has yielded approximately 150,000 tons of talc and talc-tremolite rock. The commercial bodies are in a persistent feldspar- and diopside-rich member of a highly metamorphosed sedimentary series. Igneous rocks that range from mafic to felsic in composition have extensively invaded the metasediments. Individual talc bodies, the largest of which has an 800-foot surface exposure, are narrow and lenticular, and represent a nearly complete replacement of carbonate strata.

Most of the talc is highly tremolitic, but relatively pure concentrations of the mineral talc are common next to the footwalls of the commercial bodies. Talc concentrations also occur, though less commonly, within the talc-tremolite bodies and next to their hanging walls.

In the Silver Lake province two other deposits, the Calmasil and Pomona mines, are being worked. These are in the vicinity of Yucca Grove, about 12 airline miles north-northeast of the Silver Lake mine. Here, as at Silver Lake, the talc bodies are tremolitic and represent alterations of carbonate strata in metasedimentary rocks. Here, also, igneous rocks are extensively exposed.

Talc and Soapstone Deposits of the Sierran Foothill Belt. In California the talc-rich rock obtained from deposits in the talc-actinolite schist and serpentine bodies of the western foothills of the Sierra Nevada has ordinarily been called soapstone. The high iron content typical of this material has made it unsuitable for most of the uses cited for the so-called high-grade talcs. Though mined in much smaller quantity than talcs of the eastern California belt, the soapstone has been in steady demand for many years. Relative nearness to markets and inexpensive mining favor the development of these deposits.

Since 1895 soapstone production has been recorded from 17 properties in seven Sierran foothill counties. Previously, soapstone had been mined and used as a construction material in this area, but specific data on this earlier production are not available. Most operations were small, and but few continued for periods greater than 10 years.

The Swift deposit near Latrobe, El Dorado County, was operated during the period 1916-24 and was again worked for about 4 years beginning in 1936. The Prouty talc mine, 1½ miles south of Shingle Springs, El Dorado County, was worked intermittently from 1919-28. The McLean deposit in Butte County was worked from 1923-40, and the Pacific Minerals Company deposit, about 3 miles northeast of Latrobe in El Dorado County has been worked from 1929 to the present.

Other properties contributing soapstone within the last 30 years include one in Butte County, two in Calaveras County, three in El Dorado County, one in Tulare County, two in Tuolumne County, and five in Amador County.

Miscellaneous Talc and Soapstone Deposits. Talcose material has also been produced from several other deposits scattered throughout the state. Talc deposits on Santa Catalina Island, which were worked in the eighteen-nineties, are among the first for which there is a recorded output. In 1917 and 1923 a small amount of talcose rock is reported to have been obtained from a deposit near Acton, Los Angeles County. Since 1940 talc has been intermittently obtained from the Ganim mine, a gold property near Schilling, Shasta County. The talc bodies at the Ganim mine are in an altered zone in meta-andesite.

Uses and Marketing of Talc and Soapstone. Most of the talc mined in California is milled in Los Angeles; the remainder is processed at plants in the desert area, in the San Francisco Bay area, and at Ogden, Utah. Milling consists simply of dry grinding, but care is taken to maintain standard grades. Much of the talc is sold unblended, but the blending of different talc types is a common practice.

More than half of California's current talc output is consumed by the ceramic industry. Steatite from the Inyo Range is shipped to factories in the eastern United States where it is used as the principal raw material in high-frequency insulator bodies. A large part of the production of both tremolitic and non-tremolitic talc mined in the Death Valley and Silver Lake areas is marketed as an ingredient in wall tile. The principal market for this product is in the Los Angeles area, but wall-tile talc is also shipped to other western cities. Smaller quantities of California talc are used as a raw material in other ceramic ware.

Most of the remainder of the talc produced in eastern California is consumed by the paint, rubber, and textile industries. The fibrous talcs of the Death Valley area are widely used as a paint extender and for this purpose are shipped to many out-of-state consumers. The fibrous talcs are also marketed to textile mills in the eastern United States. Talc is marketed to the rubber industry both as a filler and as a lubricant. Smaller amounts are used in insecticide carriers, in cosmetics, and for various minor industrial applications.

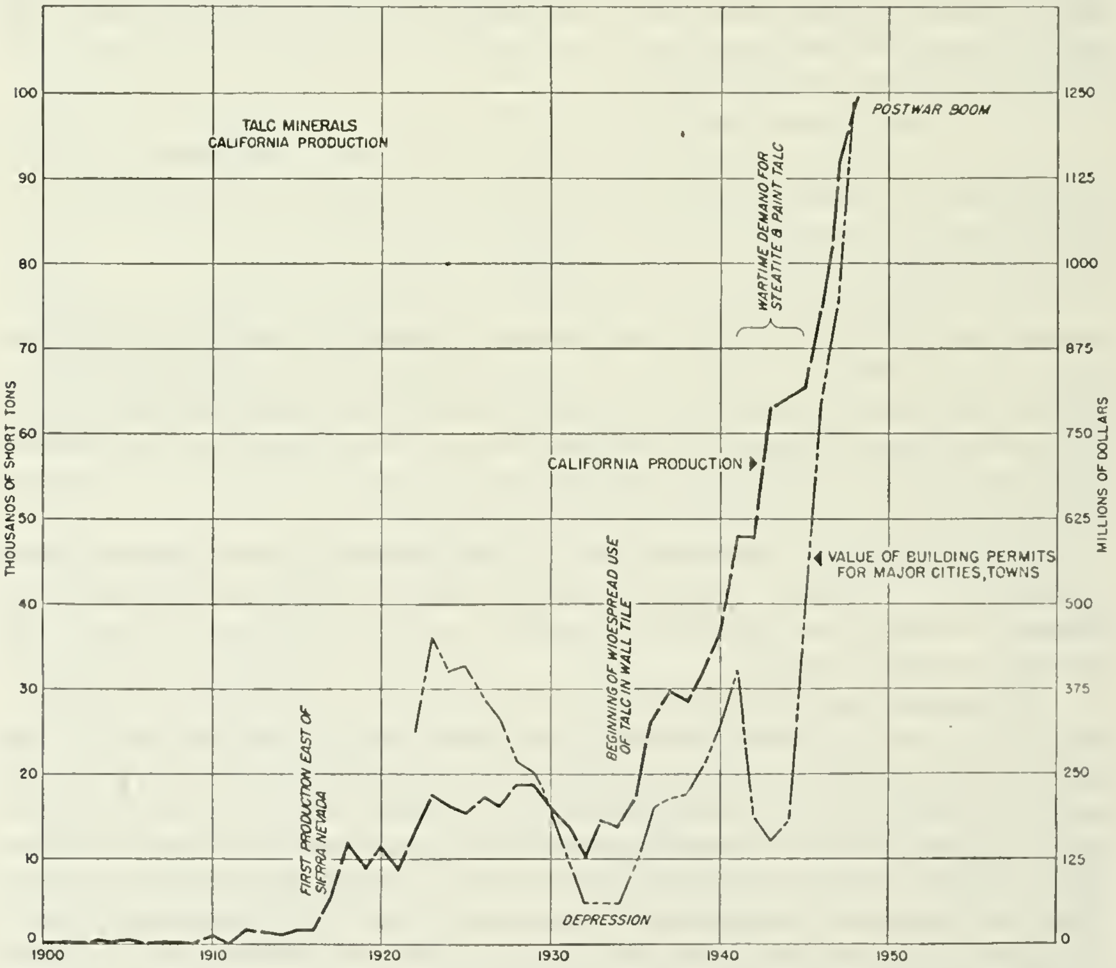

FIGURE 1. Chart showing production of talc, soapstone, and pyrophyllite in California, 1900-48, compared with value of California building permits, 1922-48.

Most of the past production of talc and soapstone from the Sierran foothill belt has been used as a filler in the manufacture of roofing. In recent years the material has been used principally as an insecticide dust.

Mining Methods. In California talc mines, underground methods are ordinarily employed, though recently a relatively large tonnage of talc at the Silver Lake mine has been removed in surface operations.

Early operations at the Talc City mine employed a glory-hole method, but underground caving was later used. More recently the ore has been removed from overhand stopes that are supported by timbers where necessary.

In the early development of most of the talc mines in the southern Death Valley-Kingston Range area adits were employed. But in their later histories mining by shafts or winzes has become necessary. Production at the Western mine is currently obtained through inclined shafts spaced at intervals along the talc body. From these and appended cross-cuts, drifts have been driven along the deposit. Most of the talc has been removed by overhand stoping. A similar method has been employed at the Superior mine.

The Monarch mine has been developed by successively longer adits that have encountered the deposits at successively deeper points. Square-set timbers have been extensively used in stoping at this property. The talc bodies at Warm Spring are mined by closely spaced parallel adits driven from a canyon wall. The adits are joined by low-angle raises that are progressively enlarged to form a modified room and pillar system.

The steeply dipping deposits at Silver Lake have been most commonly developed by shafts that are sunk to the keel of the deposits. At several levels drifts are driven to the along-strike limits of the ore bodies; the talc is removed by overhand stoping and is hoisted to the surface.

The talc and soapstone mines of the Sierran foothill belt have been chiefly quarrying operations.

Prices of Talc and Soapstone. The value of California talc as mined has been, in general, difficult to determine because the producers ordinarily market the talc after it is transported to the mill, ground, and sacked. In recent years, producers in the eastern talc belt have set values ranging from $10.00 to $18.00 per ton for material at the mine. Soapstone from the Sierran foothill belt has been valued in the range of $3.00 to $10.00 per ton at the mine.

PYROPHYLLITE

Mineralogy and Geologic Occurrence. Pyrophyllite [$Al_2Si_4O_{10}(OH)_2$] has physical and optical properties similar to those of talc; but contains aluminum instead of magnesium. In California, as elsewhere, the geological occurrences of the two minerals are dissimilar. Most of the commercial deposits of pyrophyllite have formed by alteration of acidic volcanic rocks. But pyrophyllite also has been noted in metamorphosed sedimentary rocks and in or along gold-quartz veins.

Localities. The commercial production of pyrophyllite in California was recorded for the first time in 1945. Four properties, two in Mono County and one each in Inyo and San Diego Counties, are currently active.

The two pyrophyllite properties in Mono County are in the belt of highly metamorphosed rock which contains the White Mountain andalusite deposit described in the section on andalusite, kyanite, and sillimanite in this bulletin. Pyrophyllite is now being obtained at operations near the north and south ends of a pyrophyllitic zone which is exposed for a distance of about 2 miles along the lower west face of the White Mountains east of the Shealy rail siding. The pyrophyllitic zone lies to the west of the quartzose, andalusite-bearing zone and is, itself, bordered on the west by micaceous schists. Surface exposures of the pyrophyllitic zone are commonly several hundred feet in width, though not all of the zone has yet proven to be of commercial material. Both mines are quarrying operations.

Pyrophyllite has also been obtained from a recently developed deposit about 5 miles north-northwest of Aberdeen, Inyo County. Here a pyrophyllitic layer is overlain by crinoidal limestone. The extent of the deposit is largely obscured by alluvium which overlaps it on three sides.[4]

Since 1945 pyrophyllite has been obtained from the Pioneer mine in the San Dieguito area of west-central San Diego County. The pyrophyllite bodies are elongate lenses representing the alteration of Jurassic (?) volcanic rocks which are intermediate to felsic in composition.[5] Exposures of the pyrophyllite-bearing volcanics are confined to an area of approximately 1 square mile. The primary layering in the volcanics and the long direction of the pyrophyllite lenses generally strike northwest.

The highest grade pyrophyllite schist is a lens at least 150 feet long and 15 feet in average thickness. The main workings are open cuts and have been developed primarily in this body..

Uses of Pyrophyllite. Pyrophyllite and talc are employed in many similar uses, though in California and throughout the world talc is mined in much larger quantity.

In recent years pyrophyllite has been used principally as an insecticide diluent, and as a filler in hard rubber. It is also employed as a raw material in the manufacture of wall tile and refractory ceramic bodies. Other materials in which pyrophyllite serves effectively as a filler include roofing, cotton cordage, textiles, special plasters, paper, oilcloth and linoleum, plastics, and soap. Small amounts have been used as a base for cosmetic preparations. Nearly all of the pyrophyllite mined in California to date has been marketed as insecticide dust, but in mid-1949 material from the Huntley deposit in Mono County was being shipped to the Los Angeles area as a red-burning tile ingredient.

Processing and Prices of Pyrophyllite. Like talc, pyrophyllite is dry-ground to a fine size and to standard grades. California operators have valued unground pyrophyllite at the mine in the range of $10 to $20 per ton.

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[4] Oakeshott, G. B., oral communication.

[5] Jahns, R. H., and Lance, J. F., Geology of the San Dieguito pyrophyllite area, San Diego County, California, in preparation.

PART IV

METALS

CONTENTS

ALUMINUM

By Mort D. Turner

No metallic aluminum has been produced commercially from California raw material. Two reduction plants operated in California during World War II, but both used alumina (Al_2O_3) derived from South American bauxite. One of the plants, at Riverbank, Stanislaus County, was active from May 1943 to August 1944; the other, at Torrance, Los Angeles County, was active for 2 years, beginning in July 1942.[1]

Aluminum metal is produced by the electrolysis of alumina, a process discovered by Hall in 1886 and never supplanted. Bauxite is a commonly pisolitic, clay-like material composed of hydrous aluminum oxides. It serves as the source material for almost all the domestic production of alumina. Considerable interest has been shown, however, in the recovery of metallurgical-grade alumina from high-alumina clay (hydrous aluminum silicates), siliceous bauxite, anorthosite (a rock composed almost wholly of plagioclase, commonly labradorite), and diasporic clays (clays containing the mineral diaspore, $HAlO_2$).

Reduction Processes. The Bayer alkaline process, the one generally used to recover alumina from bauxite, is not applicable to the other aluminum-rich materials. The relatively high silica contents of such materials (up to 50 percent SiO_2 in contrast with about 5 percent for the usual bauxite used) cause a high loss of alumina through the formation of unusable sodium-aluminum silicate. In the Bayer process bauxite is digested in a hot concentrated solution of sodium hydroxide which dissolves alumina but not the silica and iron compounds present. From this solution aluminum hydroxide is precipitated, filtered, and calcined to produce relatively pure alumina.[2]

One of the most promising of the processes developed for recovery of alumina from high-silica sources is the lime-soda-sinter process. This process involves the formation of a water-soluble sodium aluminate and

> "a water-insoluble calcium silicate compound by sintering the proper proportions of finely ground ore, limestone, and soda ash. The resultant sinter is ground relatively coarsely and is leached with alkaline solutions to dissolve the sodium aluminate compound and then filtered * * * The extracted liquor * * * contains small amounts of dissolved silica which must be removed by autoclaving * * * The alumina is precipitated as trihydrate by passing a mixture of CO_2-gas and air through the purified extract liquor. The trihydrate is then calcined to form anhydrous aluminum oxide, which is used as the cell feed in the production of airplane-grade aluminum metal. The end liquors of the process are treated for the removal of impurities such as potassium sulfate and for soda ash recovery, which is essential for economical operation."[3]

Metallurgical-grade alumina derived from either bauxite or the aluminum silicates (such as high-alumina clay and anorthosite) is converted into aluminum by the Hall process. In this process the alumina is dissolved in molten cryolite (Na_3AlF_6) in an electrolitic cell where the aluminum is reduced to the metallic state.

Geology and Occurrences. Bauxite, the most important ore of aluminum, is a product of rock decay, as are the clay minerals. It occurs as

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[1] Dolbear, S. H., Economic mineral resources and production of California: California Div. Mines Bull. 130, p. 75, 1945.

[2] DeMille, J. B., Strategic minerals, pp. 30-48, New York, McGraw-Hill Book Company, Inc., 1947.

[3] Brown, R. A., and others, Recovery of alumina from Wyoming anorthosite by the lime-soda-sinter process: U. S. Bur. Mines Rept. Inv. 4132, p. 5, 1947.

gray, yellow, or brown earthy or pisolitic masses. Frequently the aluminum hydroxides gibbsite [$Al(OH)_3$] and diaspore ($HAlO_2$) are present; silica and iron oxides are common impurities.

Low-grade bauxite, bauxitic clay, and high-alumina clays (hydrous aluminum silicates) form 95 percent of the potential aluminum reserves (exclusive of anorthosite) of the United States [4] although they are not presently being used for the production of aluminum.

The silica content of California ceramic clays ranges from 30 to 75 percent; the alumina content ranges from 46 to 15 percent.[5] For the production of metallurgical-grade alumina, clays high in alumina and low in silica and iron are the most desired. The maximum theoretical alumina content in a pure clay would be 40 percent.[6] Clays that have higher proportions of alumina, such as the Jones Butte fire clay at Ione, Amador County, with 42.21 percent Al_2O_3, the high-alumina bone at Alberhill, Riverside County, with 46.52 percent Al_2O_3, and several others at Alberhill with from 41 to 43 percent Al_2O_3,[7] apparently contain aluminum hydroxides, and thus are bauxitic clays.

Aluminum hydroxides are known to form only in soils of tropical areas. During the Tertiary period hot humid climates existed in several parts of the world which are now temperate. Several of these areas, such as Arkansas, Georgia, France, and Hungary, contain important bauxite deposits. Such conditions also prevailed in California during the Paleocene and Eocene epochs (early Tertiary) when high-alumina clays formed over large areas of the state. At this time less extensive deposits of laterite (a mixture of hydroxides of iron and aluminum and some free silica [8]) and bauxitic clay were also formed. The high-alumina clays of the state are generally confined to the Ione,[9] Tesla,[10] and Martinez [11] formations, all of which are Paleocene or Eocene in age.

The Ione formation outcrops along the west side of the Sierra Nevada in a long, narrow, discontinuous belt from Butte County on the north to Madera County on the south. High-alumina clays occur throughout this area and are commercially produced as ceramic material at the following localities: Lincoln, Placer County; Michigan Bar, Sacramento County; Ione, Amador County; Valley Springs and Knights Ferry, Calaveras County; and in Tuolumne County near Cooperstown. Occurrences of laterite and bauxitic clay in the Ione formation have been noted only in the vicinity of Ione.

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[4] Davis, H. W., and Trought, M. E., Bauxite: Minerals Yearbook 1946, p. 178, 1948.

[5] Dietrich, W. F., The clay resources and the ceramic industry of California: California Div. Mines and Mining Bull. 99, pp. 354-355, 1928.

[6] Ross, C. S., and Kerr, P. F., The kaolin minerals: U. S. Geol. Survey Prof. Paper 165-E, pp. 163-165, 1948.

[7] Dietrich, W. F., op. cit., pp. 354-355.

[8] Lindgren, Waldemar, Mineral deposits, 4th ed., p. 374, 1934.

[9] Allen, V. T., The Ione formation of California: Univ. California Dept. Geol. Sci. Bull., vol. 18, pp. 347-448, 1929.

Dietrich, W. F., op. cit., pp. 49-63.

Bates, T. F., Origin of the Edwin clay, Ione, California: Geol. Soc. America Bull., vol. 56, pp. 1-38, 1945.

[10] Huey, A. S., Geology of the Tesla quadrangle, California: California Div. Mines Bull. 140, pp. 33-38, 60, 1948.

Dietrich, W. F., op. cit., pp. 42-46.

Allen, V. T., Eocene anauxite clays and sands in the Coast Ranges of California: Geol. Soc. America Bull., vol. 52, pp. 271-294, 1941.

[11] Engel, René, Economic map of Lake Elsinore quadrangle: California Div. Mines, 1949.

Dietrich, W. F., op. cit., pp. 161-182.

Richard, L. M., California clays require special treatment to meet metallurgical demands: Pacific Min. News, vol. 1, no. 1, p. 13, 1922.

A United States Bureau of Mines drilling program, begun in 1942, explored a small high-alumina clay area near Ione. This project revealed an estimated 53,800,000 tons of clay averaging 23.6 percent Al_2O_3 and 2.4 percent Fe_2O_3 on a dry basis.[12]

The presence of additional high-alumina clay in the Ione area is recorded by previous workers.[13] The clays and other sediments of the Ione formation were derived from deeply weathered Sierran rocks to the east. The products of weathering were transported westward and, in places, deposited on a previously formed lateritic surface. There are indications at the Newman pit at Ione that some lateritization also took place during Ione time.

The Eocene beds which include the Tesla formation are exposed in portions of the Diablo Range that lie in northern Contra Costa County and eastern Alameda County. Clays with sufficiently high alumina contents to be utilized in the manufacture of refractories have been mined from this formation in the past [14] and reserves of high-alumina clay are known to exist at Tesla, Alameda County. These clays are composed of material which originated in the Sierra Nevada to the east. They are similar to and may have been deposited at nearly the same time as the clays of the Ione formation.

The Martinez formation of the Alberhill-Corona district in western Riverside County contains large quantities of high-alumina clay, and small amounts of bauxitic clay and high-silica bauxite. The Martinez formation was deposited during the Paleocene epoch under conditions similar to those of the Ione and Tesla formations.

The United States Bureau of Mines has published a description of experimental and pilot-plant research done during World War II on the problem of producing metallurgical-grade alumina from Wyoming anorthosite.[15] The results indicate that the lime-soda-sinter process would probably be practical for alumina extraction from anorthosite under favorable economic conditions or strategic necessity. Anorthosite contains from 25 to 30 percent alumina. This percentage is comparable to the alumina content of high-alumina clay. The very large masses of anorthosite in the western San Gabriel Mountains of southern California, therefore, constitute a potential, though at present a noncommercial, aluminum reserve. The only available analysis of California anorthosite, from a sample in the western San Gabriel Mountains near Alpine, Los Angeles County, gives silica 58.10 percent and alumina 28.27 percent.[16]

Uses. Aluminum is a very desirable metal because of its lightness. It also has such other useful properties as corrosion resistance, ductility, high electrical and thermal conductivity, and high reflective power. Aluminum has only about half the tensile strength of copper; but, because of the difference in weight, electric cable made of aluminum will support itself over longer spans than copper cables of the same diameter. An

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[12] Wimmler, N. L., and others, Exploration of five western clay deposits: Am. Inst. Min. Met. Eng. Trans., vol. 173, p. 147, 1948.

Johnson, F. T., and Ricker, Spangler, Ione-Carbondale clays, Amador County, California: U. S. Bur. Mines Rept. Inv. 4213, 6 pp., 1948.

[13] Allen, V. T., op. cit., pp. 375-382.

Dietrich, W. F., op. cit., pp. 354-355.

Bates, T. F., op. cit.

[14] Cronise, T. F., The natural wealth of California, p. 629, 1868.

[15] Brown, R. A., and others, op. cit., 127 pp.

[16] Tucker, W. B., Los Angeles field division—Los Angeles County: California Min. Bur. Rept. 23, p. 322, 1927.

alloy of aluminum with 4 percent copper, called Duralumin, combines the lightness of aluminum with the strength and toughness of steel and is extensively used in structural members. Elemental aluminum and aluminum alloyed with silicon, nickel, iron, titanium, or maganese are used in almost all industries, especially aircraft, other transportation industries, and construction.

Marketing. Large amounts of aluminum have been consumed in the California construction and manufacturing industries, but during World War II the metal greatly increased in importance in the state because of the concentration of aircraft production in the Los Angeles area. In an attempt to alleviate the serious aluminum shortage which developed, the federal government built the two previously mentioned aluminum reduction plants in California, one at Torrance and the other at Riverbank, at a combined cost of \$35,600,000. Both were operated by the Aluminum Company of America. Because of labor shortages, neither plant operated at capacity at any time. With an annual capacity of 128,000 tons a year, they produced 121,750 tons of metallic aluminum between 1942 and 1944. Both plants are now idle, but bids for their purchase are being entertained by the government from prospective buyers. Shortage of electric power and its high cost are among the factors preventing the post-war operation of these plants. It was estimated[17] that cost per pound of aluminum at Torrance was 12.63 cents as compared with 10.63 cents in the Pacific Northwest.

From 1941 until late 1946 the price of commercial and mill ingot, delivered, was 15 cents a pound. On January 12, 1950, base price, f.o.b New York, was 17 cents a pound.[18]

ANTIMONY

By L. A. Norman, Jr.

Though antimony occurs at numerous localities in California, and was mined as early as 1887, only a few hundred tons of the metal have been obtained from sources within the state. More than half of the total output was mined during the period 1915-17 under high war-time prices. Since World War I, antimony production in California has been negligible, notwithstanding the urgent demand and high prices of World War II. Antimony concentrates from out-of-state sources, however, were smelted in California. Deposits in Kern and Inyo Counties have been the principal antimony sources in the state.

Mineralogy and Geology. Stibnite (Sb_2S_3) is the only antimony mineral of commercial importance, although its oxidation products, cervantite (Sb_2O_4), senarmotite (Sb_2O_3), and valentinite (Sb_2O_3) contribute to the value of some ores. Tetrahedrite [$(Cu,Fe)_{12}Sb_4S_{13}$], jamesonite ($2PbS \cdot Sb_2S_3$), and pyrargyrite ($3Ag_2S \cdot Sb_2S_3$), are among the many antimony minerals of minor importance as sources of antimony.

Stibnite ordinarily occurs in veins and complex fracture zones, but stibnite-bearing replacement deposits in shale and limestone are common. Most stibnite deposits have formed at relatively low temperatures at shallow depths, though some occur within or near intrusive igneous rocks and are believed to have had a more deep-seated origin.

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[17] DeMille, J. B., op. cit., p. 36.

[18] Eng. and Min. Jour. Metal and Mineral Markets, vol. 21, no. 2, New York, McGraw-Hill Publishing Co., Inc., Jan. 1950.

Nearly all of the stibnite that has formed in the near-surface veins is accompanied by a quartz gangue. Other minerals commonly present, though in small amounts, are pyrite (FeS_2), sphalerite (ZnS), arsenopyrite ($FeAsS$), tetrahedrite ($3Cu_2S \cdot Sb_2S_3$), and cinnabar (HgS); minor amounts of silver and gold also may be present in these veins. Though stibnite-bearing veins are widespread, most of the stibnite is pockety and irregular and is not in large concentrations.

In some replacement deposits, stibnite is subordinate to galena and other lead-bearing minerals. Also, stibnite and cinnabar may be found together in hot-spring deposits.

Small, scattered deposits of antimony occur in several localities in California, the principal ones being in Kern, San Benito, Inyo, and San Bernardino Counties. Antimony deposits in the San Emigdio Canyon area, Kern County, are mainly stibnite-quartz veins which carry some gold. Native antimony has been reported from this area.[1]

In the central part of the Stayton district, which includes parts of San Benito, Santa Clara, and Merced Counties,[2] veins containing stibnite and cinnabar occur in basaltic rocks along faults.

Antimony deposits of the Wildrose Canyon area of Inyo County were formed in chlorite schists and amphibolite at shallow depths and at low temperatures. The ore is concentrated in fractures and shear zones along limbs and crests of anticlines.[3] Other antimony deposits in California have been tabulated by Murdoch and Webb.[4]

The largest reserves of antimony in the United States are in the Yellow Pine district of Idaho, principally at the Yellow Pine mine. Other antimony deposits occur in the Humboldt Range, Nevada; in Baker County, Oregon; and in Garfield County, Utah.

Most of the world's production of antimony has been from China. Mexico is the second largest producer.

Utilization. Antimony has a variety of uses in both metallic and nonmetallic products. It was used by ancient man as a medicine and for makeup purposes by biblical women. At present the greatest use for the metal is as an alloying element in lead to which it adds hardness and strength. Lead alloys, in which antimony comprises from 1 to 20 percent, are used in battery plates, bearing metal, type metal, cable sheathing, solder, ammunition, sheet, pipe, and other minor products. It is adaptable to use in type metal because of its property of expanding upon cooling from a molten mass. In 1948 approximately 60 percent of the primary antimony consumed by industry was in such metal products.[5] The remaining 40 percent was consumed in nonmetallic products, of which 26 percent was used in the manufacture of frits and ceramic enamels and 21 percent in paints and lacquers. During World War II, the largest single use for antimony was as a nonmetallic product in flameproofed textiles. Other nonmetallic products using antimony include ammunition primers, glass and pottery, matches, plastics, rubber, and various chemicals.

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[1] Murdoch, Joseph, and Webb, R. W., Minerals of California: California Div. Mines Bull. 136, p. 50, 1948.

[2] Bailey, E. H., and Myers, W. B., Quicksilver and antimony deposits of the Stayton district, California: U. S. Geol. Survey Bull. 931-Q, p. 405, 1942. . . . . California Div. Mines Bull. 147, pp. 37-56, October 1949.

[3] White, D. E., Antimony deposits of the Wildrose Canyon area, Inyo County, California: U. S. Geol. Survey Bull. 922-K, p. 307, 1940.

[4] Murdoch, J., and Webb, R. W., op. cit., pp. 284-86.

[5] Antimony in 1948: U. S. Bur. Mines Mineral Industry Surveys, Mineral Market Rept., mms. 1740, 1949.

Limited substitutes for antimony include calcium as a hardening agent, and bismuth in battery plates. Cadmium, titanium, and antimony are competitive pigments.

Treatment. The extraction of antimony from its ores may involve hydrometallurgical, electrolytic, or pyrometallurgical processes, or combinations of them, depending largely upon the grade of ore. The supply of antimony for world consumption to date, however, has come almost entirely from the application of dry methods.

Low-grade ores can be concentrated by gravity separation and flotation with good results. Beneficiation of such ores by differential flotation has proved economic at the Yellow Pine mine, Idaho.

Liquation of high-grade stibnite ores (50 percent antimony) has been a common practice in China in producing crude or needle antimony. The process is simple and involves heating the charge just enough to permit the release of the antimony as molten material of low purity. Sulfide ores of lower grades are volatilized or roasted to produce a trioxide which may be either marketed as such, if purity is satisfactory, or reduced to metal. The Harshaw Chemical Company's operation at El Segundo include flash-roasting of concentrates and reduction of the trioxide in a reverberatory furnace to an unrefined metal which was later purified. At some operations, antimony metal is produced by the direct smelting of ores.

Metal produced by many of the methods is impure, termed crude or unrefined antimony, and must be treated to remove the objectional impurities such as arsenic, iron, and other metallic components. Lead is difficult to remove, and, consequently, antimony orès or crude metal containing a significant amount of lead may be converted to antimonial lead or hard lead for the trade.

*Methods generally adopted in antimony smelting.**

Type of ore	Approximate Sb content percent	Method
Sulfide	20	Volatilization
Sulfide	35	Blast-furnace method
Sulfide	50	Liquation and English precipitation
Oxide	30	Blast-furnace method
Oxide	50	Blast-furnace method
Oxide and sulfide		Blast-furnace method

* Wang, C. Y., and Riddell, G. C., Antimony, in Liddell, D. M., and others, Handbook of Nonferrous Metallurgy, 2d ed., vol. 2, p. 137, 1945.

Markets. Domestic mine production of antimony from antimony ores for 1948 was 6,489 short tons, an increase of 22 percent over 1947.[6] The Bradley Mining Company, operating the Yellow Pine mine in Idaho, accounted for 93 percent of the domestic production. Industrial consumption of primary antimony in finished products amounted to 15,455 tons during the year.

Domestic primary antimony smelters produced 14,308 short tons of metal, oxide, and sulfide in 1948, an increase of 4 percent over the previous year. Domestic primary lead smelters produced antimonial lead

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[6] Antimony in 1948: U. S. Bur. Mines, op. cit.

as a byproduct from domestic and foreign antimonial lead ores, and from scrap containing a total of 5,760 tons of antimony. Total production of antimony at secondary plants, including antimony recovered from scrap at primary lead smelters, was 21,812 short tons (preliminary). Imports of antimony ore, liquated antimony, antimony metal, type metal, and antimonial lead in 1948 was 18,790 tons of contained metal.

The Harshaw Chemical Company, operated the only antimony smelter in California, at El Segundo. This plant which is now closed occasionally purchased small lots of California ore. The principal raw material used at this plant, however, has been concentrates from the Yellow Pine mine.

Prices for antimony continued to rise for the third successive year, being quoted at 33 cents per pound, bulk, Laredo, on January 1, advancing to 35 cents in May, and finally to 38.5 cents in October. Nominal quotations for domestic antimony ore advanced accordingly, being $4.80 and $4.90 per unit of contained antimony, 50 to 55 percent, at the end of the year.

History of Production. The antimony deposit that was discovered prior to 1850 in San Emigdio Canyon, Kern County, was the first found in the United States that promised to be of commercial value.[7] However, this and other California deposits have produced a relatively small amount of the metal, the total production from 1887 to date being valued slightly in excess of $225,000.[8]

The San Emigdio antimony mine in Kern County was first worked by the padres of the missionary period. It was reopened in 1876 and a concentrating plant and smelter were erected to treat the ores which carried silver as well as antimony.[9] This mine and other mines in the same area as well as in other districts in Kern County have been worked intermittently. Most of their productive periods have been during times of high metal prices.

During the 1915-17 antimony "boom," the Wildrose mine in Wildrose Canyon, Inyo County, was the largest antimony producer in the state.[10] Some of the ore mined here was treated at a plant in Wildrose Canyon but most of it was treated at a smelter in San Pedro. There has been little activity here since 1918.

There is no record of the small production of antimony from the Stayton district, San Benito County, which was first worked between 1870-75. Cinnabar associated with the antimony was soon discovered in the area and work was concentrated upon the more valuable quicksilver ores.[11]

BISMUTH

By Charles W. Chesterman

The total production of bismuth in California is restricted to some 20 tons produced at a copper mine in Riverside County in 1904. In order

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[7] Schrader, F. C., Epithermal antimony deposits, in Ore deposits of the Western States (Lindgren volume), p. 662, Am. Inst. Min. Met. Eng., 1933.

[8] Averill, C. V., and others, California mineral production for 1946: California Div. Mines Bull. 139, p. 32, 1948.

[9] Angel, Myron, Kern County: California Min. Bur. Rept. 10, pp. 225-26, 1890.

[10] Bradley, W. W., Mineral production for 1915: California Min. Bur. Bull. 71, p. 23, 1916.

[11] Bailey, E. H., and Myers, W. B., op. cit., p. 407.

to meet current demands of the metallurgical and pharmaceutical industries, bismuth must be imported into the state. A sharp decline in the production of domestic refinery bismuth in 1946, as compared with 1945, was accompanied by a 19 percent drop in consumption. In 1946 government stocks of metallic bismuth were reduced by 176,283 pounds; this partly off-set the production decline.

Geological Occurrence. Bismuth minerals are usually associated with other metals such as copper, gold, lead, silver, and tin in many types of vein deposits and metamorphosed calcareous sedimentary rocks. However, very little ore is mined in the United States for its bismuth content alone. Practically all of the bismuth is produced as a by-product from the smelting of lead and other base-metal ores.

Bismuth-bearing minerals in California are associated with ores of copper, lead, silver, and tungsten. In the tungsten deposits at the Darwin Hills,[1] bismuthinite and bismutite are associated with barite and scheelite in limestone. Oxidized bismuth minerals occur with garnet, epidote, clinozoisite, and other contact-metamorphic minerals in a highly metamorphosed limestone at the United Tungsten copper mine in the Morongo district, San Bernardino County.[2] Native bismuth and several oxidized bismuth minerals have been reported with arsenopyrite and gold in quartz veins at the Big Blue group of mines, Kern County.[3] At the Lost Horse mine, formerly Lang copper mine, in the Piñon Mountain District, Riverside County, bismuth sulfide occurs with copper minerals in quartz veins that cut micaceous quartzite.[4] Native bismuth, bismuthinite, and bismutite occur with tourmaline, lepidolite, and other pegmatite minerals at the gem mines in Pala,[5] Rincon,[6] and Jacumba,[7] San Diego County. A small quantity of bismuth concentrate was recovered from a tungsten mine in Fresno County.

Mineralogy. Native bismuth and bismuthinite, Bi_2S_3, are the two important minerals of bismuth. Other bismuth minerals, alteration products of native bismuth and bismuthinite, are: bismite (bismuth ocher, Bi_2O_3), 96.6 percent Bi; bismutite ($Bi_2O_3 \cdot CO_2 \cdot H_2O$), 80.6 percent Bi; and bismutospharite [$Bi_2(CO_3)_3 \cdot 2Bi_2O_3$], 81.9 percent Bi.

Utilization. The principal use of bismuth is in the manufacture of medical and cosmetic preparations. Bismuth subcarbonate and nitrate are opaque to x-rays and are taken internally before x-ray photographs are made of the digestive organs. Bismuth subnitrate, bismuth subgallate, and bismuth subsalicylate are used extensively in cosmetic preparations, soothing of intestinal disorders, and the treatment of venereal diseases.[8]

Bismuth metal alloys readily with cadmium, zinc, and lead to form many useful alloys. Several of these alloys have relatively low melting

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[1] Wilson, L. K., Tungsten deposits of the Darwin Hills, Inyo County, California: California Div. Mines Rept. 36, p. 413, 1940.

[2] Hess, F. L., and Larsen, E. S., Contact metamorphic tungsten deposits of the United States: U. S. Geol. Survey Bull. 725, p. 261, 1922.

[3] Prout, J. W., Jr., Geology of the Big Blue group of mines, Kernville, California: California Div. Mines Rept. 36, p. 413, 1940.

[4] Tucker, W. B., and Sampson, R. J., Riverside County: California Div. Mines and Mining Rept. 25, p. 483, 1929.

[5] Waring, G. A., The pegmatite veins of Pala, San Diego County (California): Am. Geologist, vol. 35, p. 362, 1905.

[6] Rogers, A. F., Minerals from the pegmatite veins of Rincon, San Diego County, California: Columbia Univ. School of Mines Quart., vol. 31, p. 208, 1910.

[7] Sanford, Samuel, and Stone, R. W., Useful minerals of the United States: U. S. Geol. Survey Bull. 585, p. 25, 1914.

[8] The condensed chemical dictionary, New York, Reinhold Publishing Corp., 1942.

points and are therefore used in sprinkler systems, safety plugs, and other devices.

Some of the bismuth alloys are widely used in the making of precision castings because the alloys expand upon cooling. Bismuth alloys are also used in solders, electrical circuits, and as coatings for selenium rectifiers. Metallic bismuth is used in the manufacture of high-refractive glasses.

Markets and Production. A large part of the bismuth consumed in the United States is obtained from the refining of copper, gold, lead, silver, and tungsten. The principal smelters where refined bismuth is produced are[9] American Smelting & Refining Company, Omaha, Nebraska; Bunker Hill and Sullivan Mining Company, Kellogg, Idaho; International Smelting & Refining Company, East Chicago, Illinois; and United States Smelting, Refining, and Mining Company, East Chicago, Illinois.

The Cerro de Pasco Copper deposit, Peru, is the world's largest producer of bismuth, as well as the principal consumer and domestic importer of bismuth.[10]

The only recorded marketing of bismuth mined in California is that of the 20 tons obtained from the Lost Horse mine, Riverside County, in 1904. This was valued at $2,400. Several hundred pounds of bismuth concentrate were made at a tungsten mine in Fresno County in 1942, but no shipments were made.

In 1949, the New York market [11] quotation on refined bismuth metal in ton lots was $2 per pound.

CADMIUM

By James W. Vernon

Though cadmium minerals have been noted at several California localities, the state's entire commercial production is confined to several thousand pounds derived as a by-product from Shasta County copper-zinc ore in 1917-18, and to an undetermined amount similarly obtained from Butte County ores which were shipped out of the state in 1944.[1] Future cadmium production in the state will undoubtedly be closely linked with activity in zinc-producing mines.

Greenockite (CdS), the chief cadmium ore mineral, is always associated with ores containing zinc. Greenockite, in California,[2] is associated with sphalerite in the Big Bend mine, Butte County; in copper-zinc ores of Shasta County; with limonite, hemimorphite, and quartz in the Cerro Gordo mine, Inyo County; and in the Crestmore quarry, Riverside County. Xanthochroite is amorphous cadmium sulfide; it is found as a thin coating on sphalerite. Other cadmium minerals are cadmium oxide and otavite (a basic cadmium carbonate).

In recent years the United States has supplied approximately 8,000,000 pounds per year or two-thirds of the world's cadmium produc-

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[9] Averill, C. V., and others, California mineral production for 1946: California Div. Mines Bull. 139, p. 34, 1948.

[10] Mote, R. H., Bismuth: Minerals Yearbook 1946, pp. 187-189, 1948.

[11] Eng. and Min. Jour., vol. 150, no. 4, p. 101, 1949.

[1] Averill, C. V., and others, California mineral production for 1946: California Div. Mines Bull. 139, pp. 34-35, 1948.

[2] Murdoch, Joseph, and Webb, R. W., Minerals of California: California Div. Mines Bull. 136, p. 164, 1948.

tion. Cadmium is always produced as a by-product; no commercial deposits of cadmium minerals alone are known. Zinc concentrates from the Tri-state region average 0.35 percent cadmium; western concentrates seldom contain more than 0.2 percent cadmium.[3]

Domestic cadmium is recovered from sludges of electrolytic zinc plants, from flue dusts of lead smelters treating zinciferous concentrates, and from the distillation of zinc ores.

The most important uses of cadmium are in electroplating, pigments, and bearing alloys. A protective coating of cadmium on steel is superior in many ways to zinc for this purpose. The cadmium compounds sulfaselenide and cadmium sulfide are used for producing red and yellow colors respectively, in paints, tires, ceramics, ink, and other products. Cadmium-nickel and cadmium-silver alloys are used in bearings that operate at high speed and high temperatures. Some cadmium is used in low-melting-point alloys for sprinkler systems and solders.

Post-war demands for cadmium have forced the price up from 90¢ per pound in early 1946 to $2 per pound in 1949.[4]

CHROMITE

By Richard A. Crippen, Jr.

Since 1869, when chromite production was first recorded in California, 434,499 short tons of chromite and chromite ore [1] have been produced in the state. Approximately three-quarters of the production was mined during World Wars I and II; most of the remainder was mined during the period 1869-95. The total output, which is the largest of any state, is valued at nearly 13 million dollars. The entire U. S. production of chromite has always fallen far short of supplying the domestic requirements, even under the high prices and lowered grade requirements of wartime. Nevertheless, the chromite produced in California during the two World Wars was a significant contribution, and in the event of another emergency the industry would undoubtedly revive. The state's estimated chromite reserves, however, are considerably less than those of Montana or Oregon,[2] and many of the known ore bodies of high-grade chromite in the state have been worked out.

Mineralogy and Geologic Occurrence. Chromite, a member of the spinel group, is the only ore mineral of chromium. It rarely conforms to its theoretical formula, $FeCr_2O_4$, but consists of an isomorphous series of oxides of chromium, magnesium, aluminum, and iron. The formula is better written $(MgFe)O \cdot (Cr,Al,Fe)_2O_3$. Ores consisting entirely of the mineral chromite range from less than 30 to more than 60 percent chromic oxide.[3]

Nearly all chromite deposits are magmatic segregations in the ultramafic rock, peridotite, or in serpentine derived from peridotite. The principal exceptions are the accumulations of chromite in black-sand

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[3] Mote, R. H., Cadmium: Minerals Yearbook 1947, p. 187, 1949.

[4] Eng. and Min. Jour., Metal and Mineral Markets, vol. 20, no. 24, New York, McGraw-Hill Publishing Co., Inc., June 1949.

[1] Until 1919 chromite production in California was recorded in net tons of the mineral; since 1919 the tonnage has been recalculated to a theoretical ore containing 45 percent Cr_2O_3.

[2] Johnson, A. C., Nighman, C. E., and Peoples, J. W., Chromite, in Mineral resources of the United States, pp. 77-81, Washington, Public Affairs Press, 1948.

[3] Stevens, Rollin E., Composition of some chromites of the western hemisphere: Am. Mineralogist, vol. 29, pp. 1-34, 1944.

deposits. Peridotite is composed of olivine and pyroxene in all proportions and almost always contains a little disseminated chromite as an accessory mineral. Most of the commercial concentrations of chromite occur in masses of dunite, a peridotite composed largely of olivine. Ore bodies are irregular or are shaped as pods or elongate lenses.

In California two general types of chromite deposits are recognized.[4] One type contains ore with little gangue and is generally irregular in shape. The ore in some of these deposits is composed of closely spaced marble-sized spheroids or ellipsoids of chromite in dunite or serpentine, and is known by several descriptive names among which "leopard" ore probably is the most popular. In the other type chromite is disseminated in relatively regular zones. Deposits of the first type that have been mined in California have yielded as much as 20,000 tons of ore, but most are much smaller. "All ranges of composition are found in the disseminated deposits, from a few scattered grains of chromite to material that is nearly all chromite." [5]

Localities. Commercial concentrations of chromite in California are contained in peridotite or serpentine derived from peridotites. The chromite-bearing areas, therefore, coincide with the areas in which these rocks are exposed. These exposures are limited to the Klamath Mountains, the Coast Ranges and the Sierra Nevada. No large bodies of ultrabasic rocks are exposed in northeasternmost California in the areas east of the Sierra Nevada, or in the southeasternmost portion of the state.

In the Coast Ranges the ultramafics have intruded rocks of the Franciscan (Jurassic) formation; in the Sierra Nevada, rocks of the Amador (Jurassic), Mariposa (Jurassic), and older formations; and in the Klamath Mountains, Jurassic and older rocks.

More than 1200 chromite deposits have been noted in California. Of these, 46 deposits are reported to have each shipped more than 1000 tons of ore to date. Eighteen of the 46 are scattered along the Sierran serpentine belt from the vicinity of Magalia, Butte County, southward to the area northeast of Fresno, Fresno County; 13 are in the Klamath Mountain counties. The other larger mines are unevenly distributed along the Coast Ranges belt between southwestern Tehama County and west-central San Luis Obispo County.

The principal chromite-producing counties listed in the order of total production previous to 1942, are San Luis Obispo, Del Norte, El Dorado, Shasta, and Fresno. Properties that have yielded more than 5000 tons of chromite ore include the French Hill and High Plateau mines, Del Norte County; the Coggins mine, Siskiyou County; the Brown mine, Shasta County; the Grey Eagle group, Glenn County; the Grau mine, Tehama County; the Pilliken mine, El Dorado County; the Clara H mine, Fresno County; and the Castro and the Pick and Shovel mines, San Luis Obispo County.

During World War II the chromite deposits of California were studied in detail by members of the United States Geological Survey.

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[4] Jenkins, O. P., Outline geologic map of California showing locations of chromite properties; Economic mineral map of California no. 3—chromite, California Div. Mines, 1942.

[5] Jenkins, O. P., op. cit.

be of future strategic importance. The treatment of such ores has been studied by the United States Bureau of Mines.

The chromium used in ferrous alloys is usually as ferrochromium, produced in the electric furnace and requiring lump ore with a high chromium to iron ratio. Commercially feasible electrolytic methods, however, have been developed to produce chromium from low-grade ore. In Australia pilot-plant operations have recently obtained chromic oxide of 95 percent purity. This process involves digestion of the ore in sulphuric acid, oxidation in diaphragm-type electric cells, filtering, and washing. Iron, magnesium, and aluminum sulphate are removed as filter cake.[9]

Beneficiation of disseminated ore from some large deposits has been feasible by crushing and concentrating, but without betterment of the chromium-iron ratio. The finely ground product, though unacceptable for ferrochrome production, is suitable for refractories and chemicals. It can also be used in one electric-furnace method of stainless-steel manufacture.[10]

Production History. The beginning of chromite production in California, as in Maryland, Virginia, and Pennsylvania, is linked with the Tyson family of Maryland. Isaac Tyson, Jr., in the early eighteen hundreds, studied chromite in the French literature and examined the first known American locality near Baltimore, Maryland. Knowledge of its geological occurrence led him to the exploration of the serpentine belt of the Appalachians, and the location of numerous deposits, some of very large size. Subsequent mining of these properties under lease or purchase gave the family virtual control of chromite production in the United States and it was actually a world monopoly for over 30 years. The ore was shipped to Glasgow, Scotland, to be processed for pigments, dyes, and chemicals, till 1845, when a plant was started near Baltimore by Tyson.[11]

The first chromite ore mined in California was obtained from deposits in Del Norte County which had been discovered by a Tyson Company employee. Beginning in 1869 and continuing for 20 years, ore was shipped around the Horn to Baltimore at the rate of 1,500 to 2,000 tons annually. Deposits in San Luis Obispo, Placer, Sonoma, and Calaveras Counties were also producing some ore in this period.

Importations of Turkish chromite (discovered in 1848) accompanied by the tariff removal in 1894, brought the domestic price so low that California production ceased from 1896-99, inclusive. Production was small during the years following, most of it being used for refractory lining at California copper smelters; but during the war period 1916-18, 175,277 tons were shipped from California mines, largely to eastern steel plants. From 1921-41 a yearly average of less than 500 tons of chromite ore was mined in California. Chromite production in the state rose during World War II, and in the period 1941-45 a total of 157,519 tons was obtained.

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[9] Ramsey, R. H., General advance marks all fields in milling: Eng. and Min. Jour., vol. 150, no. 2. p. 111, Feb. 1949.

[10] Averill, Chas. V., Chromium: California Div. Mines Rept. 38, p. 73, 1942.

[11] Glenn, William, Chrome in the southern Appalachian region: Am. Inst. Min. Met. Eng. Trans., vol. 25, pp. 481-492, 1895.

COBALT

By Lewis T. Braun

Minor occurrences of cobaltite (CoAsS), erythrite ($Co_3As_2O_8 \cdot 8H_2O$), and smaltite ($CoAs_2$), have been reported from numerous localities in California,[1] but to date there has been no commercial production of cobalt in the state. Most of the discoveries of cobalt minerals have been made in well-known zones of mineralization, such as the Sierran foothill copper belt,[2] and the lead-zinc districts of southern California.[3] A few tons of cobalt ore were mined at the Mar John property in Calaveras County in 1924, but were not marketed.

For several years the annual consumption of cobalt in the United States has been in excess of 4,000,000 pounds. Domestic production of cobalt has been sporadic, and at no time has it supplied the needs of the country. In 1948 the only domestic producer of commercial cobalt was the Cornwall, Pennsylvania, mine of the Bethlehem Steel Company.[4] Here cobaltiferous magnetite occurs at the contact of a diabase sill with calcareous shale. The magnetite at this locality has been mined for many years, but only recently has the cobalt content been recovered. Cobalt has been produced intermittently from the lead region of southeastern Missouri, where sulfides of cobalt and nickel occur associated with sulfides of iron, lead, and copper. In 1945 this was the chief producing region in the United States. A large, low-grade deposit of cobalt is being developed in the Blackbird district, Lemhi County, Idaho. More than ten million pounds of cobalt have been indicated by drilling and underground exploration. The Belgian Congo-Rhodesia area accounts for approximately four-fifths of the world's cobalt production, and cobalt imported from this area constitutes the bulk of the United States supply.

The recovery of cobalt from its ores is a complex metallurgical process involving many stages. In general, the concentrated ore is roasted to produce an alloy, matte, or speiss, depending upon the type of ore. This product is then refined by involved chemical or electrochemical methods.[5]

The principal uses of cobalt in the United States, listed in order of importance, are permanent magnet alloys; high temperature, cast cobalt-chromium-tungsten type alloys; and groundcoat frit for porcelain enamel. In 1948 permanent magnets accounted for 24 percent of the national consumption. The remainder is used principally in steel alloys, especially high-speed steels, and for the manufacture of various salts, driers, and pigments.

The price of metallic cobalt has ranged from \$1.00 to \$6.00 [6] per pound during the last 50 years, averaging around \$2.00 per pound. The advent of new producers has usually resulted in a price reduction, which is offset as the new supply is absorbed. The low of \$1.00 per pound existed

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[1] Murdoch, J., and Webb, R. W., Minerals of California: California Div. Mines Bull. 136, pp. 114, 139-140, 275, 1948.

[2] Logan, C. A., Sacramento field division—Calaveras County: California Min. Bur. Rept. 21, p. 142, 1925.

Laizure, C. McK, San Francisco field division—Madera County: California Div. Mines and Mining Rept. 24, p. 343, 1928.

[3] Sampson, R. J., Mineral resources of Los Angeles County: California Div. Mines Rept. 33, p. 175, 1937.

[4] Williston, S. H., Ferro-alloys and other strategic metals: Min. Cong. Jour., vol. 35, no. 2, p. 68, 1949.

[5] Young, R. S., Cobalt: Am. Chem. Soc. Mon. 108, New York, Reinhold Publishing Co., 1948.

[6] Tyler, P. M., Cobalt: U. S. Bur. Mines Inf. Circ. 6331, pp. 25-26, 1930.

for a short time after rich cobalt ores were found in Ontario. The high of \$6.00 per pound was in effect during the post-war boom in 1920-21. In May 1949, metallic cobalt was selling for about \$1.80 per pound.[7]

COPPER

By John C. O'Brien and James W. Crosby, III

More than 600,000 tons of copper have been obtained from deposits in California since 1860 when the metal was first mined in the state. This output is dwarfed by the production of the large copper deposits in other western states; but it is valued second only to that of gold among the metals produced in California. From 1897 to 1930 a yearly average of approximately 16,000 tons of copper was produced in the state, but the low prices of the period 1931-36 caused a marked drop in copper output. Only in 1944 did the production again exceed 10,000 tons. Despite the encouragement of unusually high prices which have extended beyond World War II, copper production in California dwindled to 450 tons in 1948. The depletion of known reserves, coupled with high operating costs, has been the principal hindrance to a revival of the industry.

Many mines in California have yielded copper, but most of the production has been obtained from deposits in Shasta, Plumas, and the Sierran foothill counties.

Mineralogy. Of some 150 known copper minerals, about 16 may be considered to be of economic importance, and 6 minerals are the source of more than 95 percent of the copper mined in North America.

The ores of copper can conveniently be divided into four groups, which are the sulfide ores, the oxidized ores, the complex ores, and the native copper ores. Most of the world's copper is derived from the sulfide ores, of which chalcopyrite ($CuFeS_2$), containing 34.5 percent copper, is the most important and widely distributed copper mineral in North America. Other copper sulfide minerals include chalcocite (Cu_2S), bornite (Cu_5FeS_4), covellite (CuS), enargite [$Cu_3(As,Sb)S_4$], and tetrahedrite [$(Cu,Fe)_{12}Sb_4S_{13}$].

The oxidized copper ore minerals include malachite [$CuCO_3 \cdot Cu(OH)_2$], azurite [$2CuCO_3 \cdot Cu(OH)_2$], cuprite (Cu_2O), and tenorite (CuO).

The complex ores are those ores from which two or more metals are eventually extracted and isolated. Many of the California copper ores are of this type.

Native copper is present in the oxidized zone of many ore deposits, but with the exception of the Lake Superior copper district it is seldom the principal ore mineral.

In California copper deposits,[1] chalcopyrite is the chief mineral; bornite, chalcocite, and tetrahedrite are characteristically subordinate. The copper ores are generally associated with pyrite or pyrrhotite and iron-bearing sphalerite. Galena, magnetite, and ilmenite may be present. Malachite, azurite, cuprite, and native copper are found in some deposits but they are not important ore minerals. In some deposits chalcopyrite and sphalerite are both present in commercial amounts and they must

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[7] Eng. and Min. Jour., Metal and Mineral Markets, vol. 20, no. 21, New York, McGraw-Hill Publishing Company, Inc., May 1949.

[1] Bramel, H. R., Cox, M. W., Eric, J. H., Heyl, G. R., Ransome, A. L., and Wyant, D. G., Copper in California: California Div. Mines Bull. 144, pp. 1-429, 1948.

be separated by selective flotation to make a marketable product. The copper and zinc minerals are so intimately associated in Shasta County ores that deposits containing 16 percent zinc, 2 percent copper, and 5 ounces of silver per ton were left as unprofitable to mine about 25 years ago. Progress in the technique of selective flotation now makes it profitable to mine such ores and the production of zinc has been more than a million pounds each year since 1942. All California copper deposits have some gold and silver associated with them.

General Geologic Occurrence of Copper. Most large copper deposits are of hydrothermal origin and are genetically related to igneous rocks. Replacement, in general, has been a more important factor in the formation of large deposits than has simple cavity filling. However, in most cases, both processes have been active together.

Copper deposits resulting from supergene enrichment form a very important group of ores. However, this process has played, in general, an important part in very few California deposits. In its simplest form, supergene enrichment is that process by which minerals are leached from the zone of oxidation, carried downward in solution, and deposited below the water table, thus enriching the primary ores. As a result of this process, rich ores have been made richer, lean ores have been made valuable, and deposits of copper minerals which originally would have been too low-grade to mine have been brought up to commercial grade. At least some supergene ore is generally present in most copper deposits, and in many cases only the enriched ores are mined.

In investigating copper properties, the possibility of supergene ores at moderate depth beneath the surface exposures must always be considered. A deposit that is small and of marginal grade at the surface may well become larger and considerably richer with depth.

Occurrence in California. Most of California's copper production has come from three districts. By the end of 1946, 54 percent of the state's output had come from Shasta County, 26 percent from Plumas County, and 12 percent from the Foothill belt counties.[2] Of the 12 percent contributed by the Foothill belt counties, Calaveras County has contributed 10 percent, the remaining 2 percent being divided among the other counties. Other counties which have contributed significant amounts of copper are Siskiyou, San Bernardino, Inyo, and Trinity.

By the end of 1946, six mines in the state had produced 79 percent of the total copper output. The Iron Mountain mine and the Mammoth mine of Shasta County had produced 42 percent of the state's total. The Walker and Engels mines of Plumas County, together with the Penn and Keystone-Union mines of Calaveras County, had produced 37 percent of the state's total. All other mines in the state contributed the remaining 21 percent of the total. Only eight counties in the state have had no recorded copper production; these are Kings, San Francisco, San Joaquin, San Mateo, Santa Cruz, Solano, Sutter, and Yolo.[3]

Almost all of the primary copper deposits in California have formed as veins or replacement bodies in igneous or metamorphic rocks.[4]

Most of the copper deposits in Shasta County consist of chalcopyrite which, with pyrite and sphalerite, has replaced sheared siliceous rocks.

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[2] The Foothill belt includes part of Butte, Yuba, Nevada, Placer, El Dorado, Amador, Calaveras, Tuolumne, Mariposa, Madera, and Fresno Counties.

[3] Eric, J. H., op. cit.

[4] Eric, J. H., Tabulation of copper deposits of California: California Div. Mines Bull. 144, pp. 207-210, 1948.

Some of these deposits are bodies of massive pyrite with erratically distributed chalcopyrite and sphalerite. In others the sulfide minerals are disseminated in schist or occur as vein or replacement deposits in schist or limestone.

Copper deposits in Plumas County represent hydrothermal alteration of igneous and metamorphic rocks and have commonly formed along contacts between two igneous masses or an igneous and a metamorphic mass. Tourmalinization of the wall rocks is common. Zinc minerals are not abundant.

> "The copper deposits of the Foothill belt, of which the most important part is in Calaveras County, are replacement deposits in hydrothermally altered metamorphic rocks, mainly metavolcanics. The ore bodies generally lie along steep faults within or at the contact of silicified, sericitized, and pyritized zones. Most of the deposits of the Foothill belt contain both chalcopyrite and sphalerite. The commonly associated metallic mineral is pyrite, but where the metamorphism in the country rock is middle- or high-grade, as in Madera County, pyrrhotite is present, in places exceeding pyrite in abundance.
>
> "Copper is reported in tactite in a few places, for example at the Lilyama and Pioneer mines in El Dorado County. Although these particular small deposits lie within the Foothill belt, they are geologically and mineralogically quite unlike the Foothill type; minerals present include quartz, calcite, garnet, magnetite, ilmenite, pyrite, and chalcopyrite, which occur within hornfels adjacent to granodiorite. Such copper ore results either from contact metamorphism, or from hydrothermal replacement by chalcopyrite of part of the pyrometasomatic deposit." [5]

In 1948 the Pine Creek tungsten mine[6] in Inyo County was the chief California producer of copper. The copper is associated with tungsten, molybdenum, silver, and gold in a contact-metamorphic ore body. The production of copper in Inyo County in 1948 amounted to 232,000 pounds, worth $48,720.

The mines described in the following paragraphs have been the six principal copper-producing properties in California. There are, however, 26 other mines in the state that have recorded productions exceeding 1,000,000 pounds. These mines are: the Copper Hill and Newton in Amador County; the Big Bend in Butte County; the Napoleon, North Keystone, and Quail Hill in Calaveras County; the Copper King and Fresno in Fresno County; the Pine Creek in Inyo County; the Daulton in Madera County; the Spenceville in Nevada County; the Dairy Farm and Valley View in Placer County; the Superior in Plumas County; the Copper World in San Bernardino County; the Afterthought, Balaklala, Bully Hill, Hornet, Keystone, Rising Star, Shasta King, and Sutro in Shasta County; the Blue Ledge and Gray Eagle in Siskiyou County; and the Island Mountain in Trinity County.

The Iron Mountain mine in Shasta County is located about 12 miles northwest of Redding. It is not known when the Iron Mountain gossan mass was first discovered, but it is generally believed that William Magee, a United States land surveyor, in association with Charles Camden, first secured the property as an iron mine in the early sixties.

The principal rocks in the vicinity of the Iron Mountain mine are the Balaklala rhyolite and the Copley meta-andesite, both of Devonian (?) age. Brecciation of the rhyolite took place, probably as a result of its

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[5] Eric, J. H., op. cit., p. 209.

[6] Partridge, T. F., Jr., Tungsten resources of California: California Jour. Mines and Geology, vol. 37, pp. 295-296, 1941.

cooling. The ore-bearing solutions then entered this brecciated zone and replaced the broken country rock with pyrite and some chalcopyrite, silver, and gold. Within the ore bodies replacement is almost complete, and at their boundaries there is a sharp change to unreplaced rhyolite. All of the massive sulfide ore contains some copper and zinc, but minable bodies of copper-zinc ore are closely associated with feeder channels along faults that existed prior to formation of the ore.[7] After deposition of the ore was complete, the covering of sediments was stripped off by erosion and the ore bodies were exposed. Supergene enrichment occurred only in the Old Mine ore body, leaving silver and gold minerals in the oxidized zone in residual concentrations. The principal minerals of the Iron Mountain gossan are iron oxides and some pyrite; in the primary ore, chalcopyrite, pyrite, and some sphalerite are predominant.[8]

The Mammoth mine is in Shasta County about 4 miles northwest of Kennett at an elevation of approximately 3,000 feet. The ore bodies occur in shear zones, mainly as flat-lying irregular lenses or tabular masses, in Balaklala rhyolite. The ore is composed of pyrite, chalcopyrite, and sphalerite, and much of it is a very massive sulfide mixture containing little quartz, which is ordinarily the principal gangue mineral. Some gold and silver are present in the primary ore. However, in the large gossan capping, gold and silver content was greater than in the primary ore. During the period that the mine was active, the ore was supposed to have averaged about 3 percent copper, and two dollars in gold and silver.[9]

The Walker mine in Plumas County was at one time the largest copper mine in California. This property is located about 10 miles southeast of the town of Genesee. The ore bodies occur in veins in fine-grained, black andalusite-garnet schist and cordierite hornfels. The main vein is traceable on the surface for more than a mile, but the barren white quartz gives little indication of the large ore bodies which lie beneath. Chalcopyrite is the principal ore mineral, but minor amounts of chalcocite and other copper-bearing minerals are in evidence. Gangue minerals are quartz, magnetite, garnet, pyrite, chlorite, and pyrrhotite. The ore is present as massive bodies of chalcopyrite in the vein quartz, as chalcopyrite replacements of the country rock, and as numerous small seams of chalcopyrite filling shears and fractures in the country rock.[10]

The Engels mine is located near the town of Engelmine, Plumas County, and is about 15 miles northeast of the town of Greenville. The ore bodies of the Engels mine occur in steeply dipping pipes which tend to be very irregular. The pipes are localized in hornblende gabbro and in younger quartz diorite which intrudes the gabbro. Pipes are also present in pre-plutonic andesites and salic lavas which have been intensively altered by contact metamorphism. The ore bodies are localized in shear zones which, themselves, were determined by the presence in the intrusive masses of roof pendants of the pre-plutonic andesite and salic lavas.

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[7] Kinkel, A. R., Jr., and Albers, J. P., The geology of the massive sulfide deposits at Iron Mountain, Shasta County, California (abstract): Econ. Geology, vol. 44, no. 1, pp. 81-82, 1949.

[8] Kett, W. F., Fifty years of operation by the Mountain Copper Company, Ltd., in Shasta County, California: California Jour. Mines and Geology, vol. 43, pp. 105-162, 1947.

[9] Tucker, W. B., Copper resources of Shasta County: California Min. Bur. Rept. 20, pp. 434-437, 1924.

[10] Averill, C. V., Redding field division—Plumas County: California Div. Mines and Mining Rept. 24, pp. 280-285, 1928.

Averill, C. V., Mineral resources of Plumas County: California Div. Mines Rept. 33, pp. 95-99, 1937.

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[5] Eric, J. H., op. cit., p. 209.

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Averill, C. V., Mineral resources of Plumas County: California Div. Mines Rept. 33, pp. 95-99, 1937.

Eric, J. H., op. cit., p. 290.

The ores consist for the most part of bornite and chalcopyrite, with much contemporaneous magnetite and ilmenite, in gangues of pneumatolytically altered country rock. The presence of gold and silver in the ore has added considerably to its tenor.[11]

The Penn mine is in northwestern Calaveras County, about 3 miles northwest of Copperopolis. The rocks in the Penn mine area consist of metasedimentary and metavolcanic rocks of Jurassic age which have been intruded by quartz porphyry. The bedding, cleavage, and schistosity all strike northwestward and dip steeply to the northeast. Two types of faulting are recognized in the immediate area of the mine. These are steeply dipping faults which parallel the schistosity, and reverse faults which dip at a low angle. The known copper and zinc sulfide bodies at the Penn mine are within, or at the contact of, irregular hydrothermally altered zones developed in the metavolcanic and intrusive rocks. The ore bodies occur in these zones of alteration as steeply pitching lenses which represent sulfide replacements of the country rock.

> "Their pitch length ranges from 150 to 1,000 feet; breadth, from 100 to 400 feet; width, from 4 to 30 feet. The ore is a mixture of pyrite, sphalerite, chalcopyrite, and a little bornite, tetrahedrite, and galena. Gangue minerals are barite, calcite, and quartz." [12]

Carefully planned exploration at the Penn mine, and in its immediate vicinity, will almost certainly disclose additional ore reserves.[13]

The Keystone-Union mine is in southern Calaveras County near the town of Copperopolis. The rocks in this area include slates and metavolcanic schists of probable Jurassic age. A lenticular mass of granodiorite is exposed about 200 feet west of the mine. East of the grandiorite, and in part contiguous with it, is an elongate mass of serpentine. Both of these intrusive bodies trend northwestward, paralleling the regional strike of the metavolcanic rocks they have intruded. The ore shoots are localized in a zone of intense chloritization adjacent to an east-dipping fault that is marked by a well-developed gouge zone. The ore bodies apparently occur as a series of irregular, overlapping lenses, often arranged en echelon. These lenses are composed of anastomosing veinlets and irregular streaks and masses of chalcopyrite and pyrite. The boundaries of the ore shoots are vague, and, in mining, are determined by assay values.[14]

The most likely areas for the discovery of deposits are the Shasta, Plumas, and Foothill copper belts; but deposits may also be found in other copper-bearing regions of the state, and new copper districts may well remain to be discovered.[15]

Utilization. The United States is the world's largest consumer of copper, requiring well over 1,000,000 tons of the refined metal annually. Domestic production of new and reclaimed copper is generally sufficient to meet the country's needs. However, copper imports usually are in excess of exports.

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[11] Knopf, Adolph, and Anderson, C. A., The Engels copper deposits, California: Econ. Geology, vol. 25, pp. 15-35, 1930.
Anderson, C. A., The geology of the Engels and Superior mines, Plumas County, California: Univ. California Dept. Geol. Sci. Bull., vol. 20, no. 8, pp. 293-330, 1931.
Eric, J. H., op. cit., p. 286.

[12] Heyl, G. R., and others, Penn zinc-copper mine, Calaveras County, California: California Div. Mines Bull. 144, p. 62, 1948.

[13] Heyl, G. R., and others, op. cit., pp. 61-84.

[14] Heyl, G. R., Ore deposits of Copperopolis, Calaveras County, California: California Div. Mines Bull. 144, pp. 106-108, 1948.

[15] Eric, J. H., op. cit., pp. 201-205.

Copper is one of the most widely used metals in modern industry. Its use is largely dependent upon its thermal and electrical conductivity, its ductility, its malleability, and its resistance to corrosion. However, copper has additional properties which are very desirable in a metal.

Enormous quantities of copper are used in the electrical industry annually. For such applications, copper is fabricated into wires, cables, and various fittings. Because of its high thermal conductivity, copper is used in the fireboxes of locomotive boilers and for steam pipes. Large quantities of copper are used in the manufacture of household appliances. Production of alloys annually consumes thousands of tons of the metal. To mention only a few of the more important alloys, phosphor-bronze, aluminum-bronze, brass, bell metal, gunmetal, monel metal, and constantan play a very important role in our daily lives. Copper is used in printing. The oxide and various salts of copper are used as coloring agents in glasses and ceramic glazes. Some copper salts are used in the manufacture of paints. Copper salts are used for antiseptics and insecticides. The metal has many additional uses which are too numerous to mention, and new uses are being developed daily. Although copper will undoubtedly be replaced by other substances in some of its present applications, the outlook for the future is bright, and an increase, rather than a decrease, in the use of the metal is to be expected.[16]

Markets, Treatment, and Mining Methods. The rapid growth of population and industries in California since the war has created an expanding market for copper in all forms. The California deposits are very seriously handicapped, however, because of the long distance the ores and concentrates must be shipped for smelting and refining. The principal deposits are very difficult and costly to develop to the stage where the construction of a milling plant is justified.

Much of the copper and zinc now produced in the state travels to the Atlantic coast before it comes back to California in the form of copper wires or tubing, or in brass and bronze bushings and bearings, that are used in machines built in California.

The California production of copper dropped from 25,584,865 pounds in 1944 to 4,814,000 pounds in 1947 and 900,000 pounds in 1948. The average price of copper rose from 11.775 [17] cents per pound for electrolytic copper in 1944, to 13.820 cents in 1946; to 20.958 cents in 1947; and to 22.038 cents in 1948. The demand for copper continued to be so great that Congress cancelled the import duty of 2 cents per pound until June 1951.

All California's copper deposits are mined by underground methods. Most of the ore is so intimately mixed with sphalerite that very fine grinding and selective flotation are required to make a satisfactory separation. No deposits contain ore rich enough to ship without milling. Copper concentrates are shipped to Tacoma, Washington, or to Salt Lake City, Utah, for smelting. Zinc concentrates are shipped to Great Falls, Montana.

The improvement in the selective flotation process has made it possible to make marketable concentrates of both zinc and copper sulfides from the complex ores found in the Shasta and Foothill copper belts.

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[16] Mellor, J. W., A comprehensive treatise on inorganic and theoretical chemistry, vol. 3, p. 104, 1946.

[17] Wanders, H. H., Copper: Eng. and Min. Jour., vol. 150, pp. 75-77, 1949.

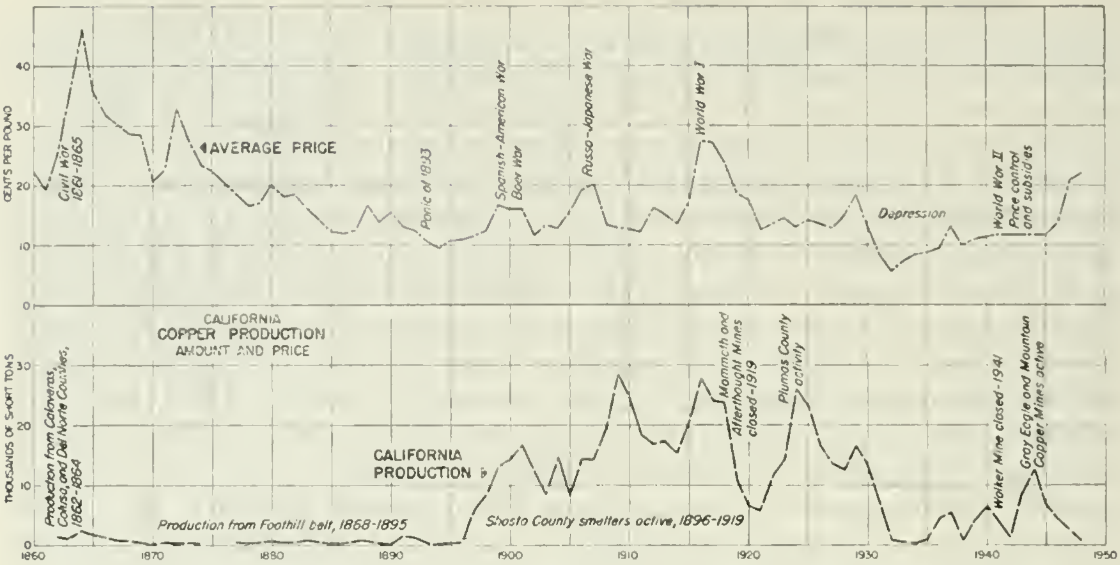

FIGURE 1. Chart showing production of copper from California and price of copper in the United States, 1860-1948.

Zinc was formerly penalized at copper smelters, but selective flotation now makes possible a marketable product of this metal. Its production in 1948 far surpassed that of copper. This advance in methods of treatment has made possible the mining of deposits which were previously unprofitable.

History.[18] The beginning of the copper industry in California dates from 1860 when Hiram Hughes,[19] searching for gold, found gossan on what was to be the Napoleon mine in the Foothill belt in Calaveras County. He sent some of the ore to San Francisco for assay and it was reported to carry 30 percent copper, worth $120.00 per ton. The miners, searching for gold, had been throwing away rich surface copper ore along the Keystone and Copperopolis lodes as worthless rock for many years. In 1861, small shipments of copper ore were made to Boston and Baltimore and one small lot was sent to Swansea, Wales, by way of New York. By the spring of 1863, considerable amounts of copper ore were being shipped from deposits near Copperopolis, Campo Seco, and Lancha Plana, in Calaveras County. The Newton mine was discovered in Amador County in 1861, and several thousand tons of high-grade chalcopyrite ore were shipped before the grade of ore decreased with depth and mining was no longer profitable. From 1862-65, Del Norte County ranked second to Calaveras County in the production of copper, and old records show that ore assaying 15 to 18 percent copper was shipped to Germany and Wales for smelting.

Copper was mined at Copper City, Shasta County, then known as Williams, in 1862. In 1863, 250 tons of ore shipped to Swansea, Wales, for treatment assayed 8 percent copper, $40.00 in gold, and $20.00 in silver, but netted only a small profit. Small quantities of copper ore were shipped from Colusa County to San Francisco from 1862-64. Some of the surface ore was very rich but the grade dropped rapidly with depth.

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[18] Aubury, L. E., The copper resources of California: California Min. Bur. Bull. 23, p. 282, 1905.

Heyl, G. R., Cox, M. W., and Eric, J. H., Penn zinc-copper mine, Calaveras County, California: California Div. Mines Bull. 144, pp. 61-84, 1948.

[19] Heyl, G. R., Foothill copper-zinc belt of the Sierra Nevada, California: California Div. Mines Bull. 144, pp. 11-29, 1948. (History of production, geology and potentialities of the Foothill copper-zinc belt.)

Transportation and smelting costs left very little profit even for the high-grade ores.

The first smelter in California was a small reverberatory furnace built in Contra Costa County in 1862. Coal from the Mount Diablo mines was used for fuel and a matte containing 45 to 48 percent copper was produced. Low-grade oxidized ores were mixed with the sulfides and the ores were not roasted before smelting. By 1868 there were nine smelting plants operating in the Foothill copper belt. A drop in the price of copper in that year, together with increased cost of mining, and lessened values in depth made copper mining unprofitable and a period of inactivity set in which lasted until 1895.

The Iron Mountain property in Shasta County[20] was originally purchased in 1894 by the Mountain Mines, Ltd., an English corporation. The property was in turn acquired by the Mountain Copper Company, Ltd., in 1896. The Mountain Copper Company has been active in mining at Iron Mountain ever since. A massive sulfide deposit was developed beneath a huge gossan outcrop. It was estimated to contain 1½ million tons of ore averaging over 7 percent copper and $2.00 per ton in gold and silver. A smelter was built at Keswick and operated until 1907, after which the ores were shipped to the company's new smelter at Martinez. Many improvements in the metallurgy of sulfide ores and improvements in the design and operation of roasting and smelting furnaces were developed by the Mountain Copper Company. Between 1901 and 1908 smelters were built and operated at the Afterthought, Balaklala, Bully Hill, and Mammoth mines. A 50-ton capacity Mace furnace was operated at the Golinsky mine for a short time in 1937.

An increase in the zinc content of the ores together with increasing costs of operation, lower prices for copper and silver, and damage suits for smoke nuisances combined to make copper mining and smelting unprofitable in the Shasta copper belt, and all the smelters were idle by 1919. A reverberatory furnace and zinc oxide plant built at Bully Hill operated for about 6 months in 1933. The production of copper declined from a high of 65,727,736 pounds in 1909 to a low of 590,638 pounds in 1934. A selective flotation plant was built at Iron Mountain by the Mountain Copper Company in 1943, which produced concentrates of both copper and zinc sulfides until June 30, 1947. The reserves of ore were exhausted in June 1947, but exploration work is being done to develop new ore bodies.

The new flotation plant of the Coronado Copper and Zinc Company started operating in October 1948. The zinc and copper concentrates are shipped out of the state for smelting. In 1919 when the Mammoth and Afterthought mines were shut down,[21] Plumas County succeeded Shasta County as California's leading copper producer.

The Engels and Walker mines were the principal copper producers in Plumas County. Both properties are now idle and their plants have been dismantled. The mines of Plumas County have produced 26 percent of the total amount of copper produced in California. The maximum of 26,950,029 pounds of copper was produced in 1925. The 1948 production was 28,000 pounds, worth $5,880.

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[20] Kett, W. F., Fifty years of operation by the Mountain Copper Company, Ltd., in Shasta County, California: California Div. Mines Rept. 43, pp. 105-162, 1947.

[21] Bradley, W. W., California mineral production for 1919: California Min. Bur. Bull. 88, pp. 37-38, 1920.

FERRO-ALLOYS

By James W. Vernon

Ferro-alloys are used principally in the production of iron and steel to serve as cleansing or deoxidizing agents, or to give the steel certain desired physical properties. Though they are also used to make alloys with metals other than iron and steel, much more ferro-alloy is consumed in the iron and steel industry than is used for all other purposes combined. Ferrosilicon is the only ferro-alloy currently being produced commercially in California. The United States Bureau of Mines is experimenting with ferro-alloy production at their pilot plant at Shasta Dam.

Ferro-alloys, including ferromanganese, silico-manganese, and ferrochromium, were first produced in California during World War I at Heroult, Shasta County, by the Noble Electric Steel Company, which utilized Shasta County iron ore and manganese and chromium ore from other parts of the state. At the same time the Pacific Electro Metals Company was producing ferromanganese at Bay Point, Contra Costa County. Neither of these operations was able to survive the general postwar economic decline.

During World War II ferrosilicon, for use in the production of metallic magnesium, was made by the Permanente Metals Corporation at its Permanente plant. Following the war the decreased demand for its use in this connection, coupled with high power rates, forced cessation of the output. On April 1, 1949, a 6-month run, producing ferrosilicon containing 75 percent silicon, was begun. Vein quartz, coke, and scrap iron are used at Permanente to make ferrosilicon. The coke and scrap iron are purchased on the market. The quartz is mined at the White Rock silica deposit, Mariposa County, California; this deposit is owned by the Permanente Metals Corporation. As there is no local market for ferrosilicon of this grade, the product is being shipped to consumers in the east.

At present about 770,000 tons of ferrosilicon are being produced annually in the United States. The iron and steel industry uses most of

*Uses and compositions of some common ferro-alloys.**

Ferro-alloy	Uses		Composition (percent) (Minor percentages of sulphur and phosphorus omitted)
	Deoxidizing steel	Alloying and to impart special physical properties to steel	
Ferromanganese	X	X	Mn 78-90, Fe 10-20, C 0.7-8, Si 1-7
Spiegeleisen	X	X	Mn 16-28, Fe 65-75, C 6.5 max., Si 1-3
Ferrosilicon	X	X	Si 15-95, Fe 5-85, C 1 max.
Silicomanganese	X	----------------	Mn 65-70, Si 17-20, C 1.5 max.
Silicon-zirconium	X	X	Zr 12-40, Si 39-52, Fe 8-45
Ferrotitanium	X	X	Ti 20-45, Al 2-9, Si 3-13, Fe 33-73
Ferrochromium	----------------	X	Cr 60-72, Fe 28-40, C 6 max.
Ferromolybdenum	----------------	X	Mo 55-75, Fe 22-43, C 2.5 max.
Ferrotungsten	----------------	X	W 70-80, Fe 20-30, C 0.6 max.
Ferrovanadium	----------------	X	V 35-55, Si 1.5-12, C 0.2-3.5, Fe 25-63

* Herzog, G. K., Metals & ferro-alloys used in the manufacture of steel: Metals Handbook, pp. 337-340, Cleveland, The American Society for Metals, 1948.

this output for deoxidizing steel during refining, to increase the resistance of cast iron to corrosion, and for the production of high-silicon steel used for electrical and spring steels.

Most ferrosilicon made in blast furnaces contains less than 15 percent silicon. Alloys richer than 15 percent silicon are made in electric furnaces. Common grades of ferrosilicon are 15, 50, 75, and 90 percent contained silicon. More of the 50 percent grade is used than any other.

Silicon used in the production of ferrosilicon is derived from quartzite, sand, or vein quartz. Iron used in this alloy is introduced as iron and steel scraps chosen for their low content of sulfur and phosphorus. The reducing agent employed in this process is either charcoal or high-grade coke.[1]

The market quotation for ferrosilicon in early 1949 was:[2] per pound of contained silicon, sold in the eastern zone, 11.3 cents for 50 percent grade, and 13.5 cents for 75 percent grade.

Almost all ferro-alloy is made in electric furnaces, although some is made in blast furnaces. In the United States ferro-alloy is produced chiefly near sources of cheap electric power in the east and south. Ferro-alloy plants have recently begun operation in Washington and Oregon, where cheap hydroelectric power is also available. The combined ferro-alloy production of New York and Pennsylvania is 60 percent of the total United States production. Other states with records of ferro-alloy production are Alabama, Iowa, New Jersey, Ohio, South Carolina, Tennessee, Virginia, and West Virginia.[3]

Ferro-alloys are being used in increasing amounts for making new types of alloys. An example is the growing use of molybdenum alloys for parts of gas turbines, jet aircraft engines, and turbo-superchargers.

Iron, molybdenum, silicon, and vanadium are the only ferro-alloy materials that are supplied exclusively from deposits in the United States. Two of the most important alloying metals, manganese and chromium, are obtained almost entirely from foreign countries. Metals not produced domestically are being stock piled by the government to insure availability of these metals if the foreign supply should be interrupted.

GOLD

By Clarence A. Logan

Since its discovery in California in 1848, gold has been the best known of the state's metallic mineral commodities. A total production of more than 100 million fine ounces, valued at approximately 2½ billion dollars, makes California the leading gold-producing state. For many years the annual gold output in California was valued higher than any single mineral product of the state; but in 1907 gold was surpassed in value by petroleum, and more recently by several other nonmetallic materials.

Except for the war years 1943 and 1944, gold has continued to be the state's most valuable metallic commodity. In these years gold was surpassed in value by tungsten, and in 1943 by quicksilver. The curtail-

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[1] Mantell, C. L., Industrial electrochemistry, 2d ed., pp. 490-501, New York, McGraw-Hill Book Co., 1940.

[2] Eng. and Min. Jour., Metal and Mineral Markets, vol. 20, no. 12, New York, McGraw-Hill Publishing Company, Inc., March 1949.

[3] Melcher, N. B., Ferro-alloys: Minerals Yearbook 1947, pp. 491-496, 1949.

ment of gold mining during World War II brought a great reduction in California gold output. By 1947 production had risen, but was still less than one-third of the nearly 1½ million ounces recovered in 1940. The principal hindrance to the recovery of gold mining has been the fixed price of gold ($35.00 per ounce) whereas operators have been faced with rising prices of other commodities, the high cost of labor and supplies, and the expense of reconditioning shut-down mines.

Mineralogy and Geologic Occurrence. Native gold is by far the most abundant of the gold minerals. It is commonly alloyed in nature with silver, and is known as electrum when the silver content exceeds 20 percent. The silver fraction in California gold averages about 12 percent; electrum is relatively rare in the state. Gold is generally massive or in thin flakes, but well-formed gold crystals are common at several lode deposits in California.

The tellurides, calaverite ($AuTe_2$), sylvanite [$(AuAg)Te_2$], and petzite [$(Ag,Au)_2Te$], have been noted at but a few localities in California and are of little commercial significance in the state.

Most primary gold deposits are closely associated with intrusive rocks of acid or intermediate composition and have originated through igneous emanations. Though some gold deposits have formed by contact metamorphism or replacement, most of them represent cavity fillings. Quartz and pyrite are the most abundant gangue minerals in the average gold deposit. Gold is also commonly disseminated in base-metal ores.

The high specific gravity of gold and its resistance to weathering allows it to be easily concentrated in placer deposits. Such deposits have been the source of much of the gold produced in California and throughout the world.

Localities. The areas in California which contain the most productive primary gold deposits are the Grass Valley-Nevada City district and the Mother Lode belt, both in the western foothills of the Sierra Nevada.

The Mother Lode belt [1] is approximately 120 miles long and averages a mile in width. It extends from northern El Dorado County southward to the vicinity of the town of Mariposa in Mariposa County, and includes more than 40 mines of importance. The gold-bearing lodes are in slate, greenstone, and schist of Jurassic and Paleozoic ages. The lodes occur within or near a system of reverse faults. Where the fault system traverses the slate, as it does in El Dorado and Amador Counties, the richest ores have been found in stringer leads or tabular veins of white quartz. In these, most of the gold is free milling. Where the faulting passes into greenstone or schist, the gold is disseminated in the country rock and most of the quartz is almost barren of gold. Much of the gold in the mineralized country rock is carried by sulfides, principally pyrite. The gold-lode deposits of Calaveras and Tuolumne Counties are ordinarily of this type.

West of the Mother Lode, the pre-Tertiary rocks consist principally of Jurassic basic intrusives and altered rocks derived from basic tuff and other volcanic debris. In places, erosion has exposed areas of the underlying intrusive granitic rocks, which range from gabbro to granite. Gold-quartz veins occur throughout this western belt, both in the meta-igneous rocks and around the borders of the granitic rocks.

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[1] Knopf, A., The Mother Lode system of California: U. S. Geol. Survey Prof. Paper 157, 1929.

East of the Mother Lode the bedrock series consists partly of a Paleozoic complex of metasediments with minor interbedded meta-igneous members, and partly of granodiorite outliers of the Sierra Nevada batholith. Schistosity, which has been impressed on all the metasediments, strikes north to northwest and dips steeply east. This region is known to miners as the East Belt. The Paleozoic rocks are clay slate and phyllite, marble, quartz-mica schist, chert, graphitic schist, and interbedded schistose meta-volcanics. The gold-bearing veins of the East Belt are generally narrower and the ore shoots are smaller than on the Mother Lode. The ores are commonly complex, and contain a variety of sulfides which may carry some copper, lead, and zinc, in addition to gold and silver.

The Grass Valley-Nevada City district, Nevada County,[2] is approximately 50 miles north-northwest of the northern tip of the Mother Lode belt. Gold-quartz veins in this area border an elongate granodiorite body which has been intruded into igneous and metamorphic rocks of Paleozoic and Jurassic age. The veins fill minor thrust faults in the granodiorite and in the invaded rocks. Quartz and pyrite are the principal minerals accompanying the gold.

The Alleghany district, in Sierra County[3] about 20 miles north-northeast of Grass Valley, is famous for the richness of its gold-quartz veins. Here, as in the Mother Lode belt, the veins fill reverse faults in metamorphic rocks.

The alluvial or placer-gold deposits, which have contributed much of California's gold output, have been formed by the erosion of pre-existing veins. The gold in the Recent placer deposits, such as those which have been extensively worked along the Yuba, Feather, and American Rivers, has been supplied in part by Tertiary placers.

These earlier placers[4] were deposited in a river system which millions of years ago eroded the area now occupied by the western slope of the Sierra Nevada. Gold released from the bedrock was concentrated in their stream beds. These rivers were first choked, and later in many places completely covered, by volcanic debris and mud-flows. Another series of streams, which developed into the present river system, was subsequently established. The present streams have swept away much of the volcanic cover, completely removed long sections of the earlier rivers, and cut new canyons which are in places 2000 to 2500 feet below the old surface. This tremendous amount of erosion resulted in the accumulation of large quantities of gold in the beds of the main streams and their branches.

The Tertiary gravels left in those sections of the old river deposits not removed by erosion have also been important gold sources. These are classed as surface placers when overburden is light enough to permit hydraulicking, and as deep placers where the volcanic cover is thick enough to require mining by tunnels or shafts. Residual placers are those where the gold has been released from the enclosing rock by rock decay, but has not been transported from the original site. The more important

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[2] Johnston, W. D., Jr., The gold quartz veins of Grass Valley, California: U. S. Geol. Survey Prof. Paper 194, 1940.

[3] Ferguson, H. G., and Gannett, R. W., Gold quartz veins of the Alleghany district, California: U. S. Geol. Survey Prof. Paper 172, 1932.

[4] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, 1911.

Jenkins, O. P., New technique applicable to the study of placers: California Div. Mines Rept. 31, pp. 193-210, 1935.

of these were along the Mother Lode, particularly in El Dorado County, and at other isolated localities, as at Scott Bar and near Happy Camp in Siskiyou County. They are locally called ''seam diggings.''

In this brief summary it is not possible to discuss all of the other sources of gold in California. In 1941 gold production was reported from 40 counties and in 1948 from 35 counties. In Shasta, Siskiyou, and Trinity counties, in the northern part of the state, both vein quartz and placer deposits have yielded large quantities of gold.

Kern County has been the principal gold source in southern California. Of the Kern County gold mines, those in the vicinity of Randsburg have been by far the largest producers. The gold deposits here are Tertiary in age and are confined to areas of Jurassic quartz monzonite and pre-Cambrian schist.[5] Where the deposits are clearly fissure fillings, the gold is accompanied by a quartz gangue.

Large quantities of gold have also been obtained from the Bodie district, Mono County. The gold-bearing veins of this district are in andesite.

Other gold-bearing areas in California include the Cargo Muchacho district in Imperial County, the Wildrose district in Inyo County, the Hayden Hill district in Lassen County, the Cove and Mojave districts in Kern County, the Hart district in San Bernardino County, and the Julian district in San Diego County.

The gold dredges of Sacramento County, where the Natomas Company is the largest operator, placed that county in the lead in gold production in 1948, with an output of $4,135,320. Natomas Company, operating six dredges, produced over $2,500,000 from gravel near Folsom and south of Natoma. Other operations included those of the Capital Dredging Company's south of Folsom, and four or five smaller bucket dredges and draglines on the American and Cosumnes Rivers.

Gold-quartz mines, worked by the Empire-Star Mines Company and the Idaho-Maryland Mines Company at Grass Valley, and by the Ancho-Erie Mining Company near Graniteville in Nevada County, were principally responsible for a production of $3,563,385 in gold, which put Nevada County in second place in 1948. Yuba County, in third place with a yield of $2,022,615, has only one large producer, Yuba Consolidated Gold Fields, which operates five large modern dredges on the Yuba River near Hammonton. Empire-Star Mines Company did some work at their quartz mines at Browns Valley. Butte, Merced, Stanislaus, and Siskiyou Counties all produced substantial amounts of placer gold from dredging operations. In Sierra County, which was in eighth place in 1948, the Original 16 to 1 mine at Alleghany has continued to be the leading producer.

The extent to which gold-quartz mining on the Mother Lode has been curtailed is indicated by the fact that Amador and Mariposa Counties were each surpassed in gold production by Trinity County, where most of the gold comes from placers. At the end of the year the Central Eureka Mining Company at Sutter Creek was the only active operator on the Mother Lode in Amador County.

Utilization. Gold is used principally for monetary purposes. Until 1934, gold coins circulated freely in the United States and to a less extent in other countries where gold served as a base for monetary systems. By

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[5] Hulin, C. D., Geology and ore deposits of the Randsburg quadrangle, California: California Min. Bur. Bull. 95, pp. 79-92, 1925.

late 1948 the United States had an official gold reserve of $24,165,000,000. The use of gold in the arts is next in importance. Such applications include the manufacture of jewelry, watches, and gold leaf. Industrial uses for gold, which stem largely from its resistance to corrosion, have been found in the electrical, dental, and chemical industries. It is believed that total world consumption for non-monetary uses is valued at about $300,000,000 a year.

Markets. Since 1934, when gold was withdrawn from circulation in the United States, the only gold that could be legally acquired, transported in the country, imported, or held in custody for domestic account without a license, has been gold in its natural state. This is defined in the regulations as gold "recovered from natural sources which has not been melted, smelted or refined or otherwise treated by heating or by chemical or electrical processes." [6] Those who make a business of buying mined gold of any kind in California are required by law to have a state license. All newly mined gold not in its natural state must be sold either to the U. S. Mint or to a licensed buyer. The mint pays a net price of $34.91¼ per fine ounce for gold and 90½ cents per fine ounce for the silver content. The silver content is usually 100 to 150 parts per 1000, and thus reduces the fineness of the gold. Gold for industrial uses is sold to licensed buyers by the government.

Gold has been in demand in parts of Europe, Africa, and Asia at prices higher than the official price of $35 an ounce. Permission has been refused to producers in the United States to send gold abroad to these markets.

Mining Methods and Treatment. The continuation of high wage levels and high costs for equipment and supplies used in gold mining, all of which were expected to decrease after the end of the recent war, have severely limited the number of mines that could continue in operation or resume work with any hope of profit. Among the lode mines, only those with better than average ores can be worked. The operators are forced by conditions to increase the use of mechanical equipment underground wherever possible. Methods of mining such as block caving and experimentation with sand filling to obviate expense of timbering have been tried. Some of the better mines can be worked at a profit only by leasing blocks of ground to selected groups of miners, with an arrangement for hoisting and milling with company equipment.

In placer mining,[7] most of the gold is now being produced by large bucket dredges. The capacity of such a dredge is so large and the crew of men needed to operate it so small that the cost of labor is spread over a large yardage, and wages paid do not greatly affect operating costs. Next to the dredge in production capacity is dragline equipment, which employs floating washing plants that use trommels and banks of riffles similar to those employed on dredges, but much smaller.

Lode gold ores are generally treated by successive amalgamation, flotation, jigging, and concentration on tables. This is followed in some instances by cyanidation of the tailing and concentrate, or shipment of the concentrate to a smelter.

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[6] U. S. Treasury Department provisional regulations issued under the Gold Reserve Act of 1934, Art. 2, sec. 19, Jan. 30 and 31, 1934.

[7] Averill, C. V., and others, Placer mining for gold in California: California Div. Mines Bull. 135, 1946.

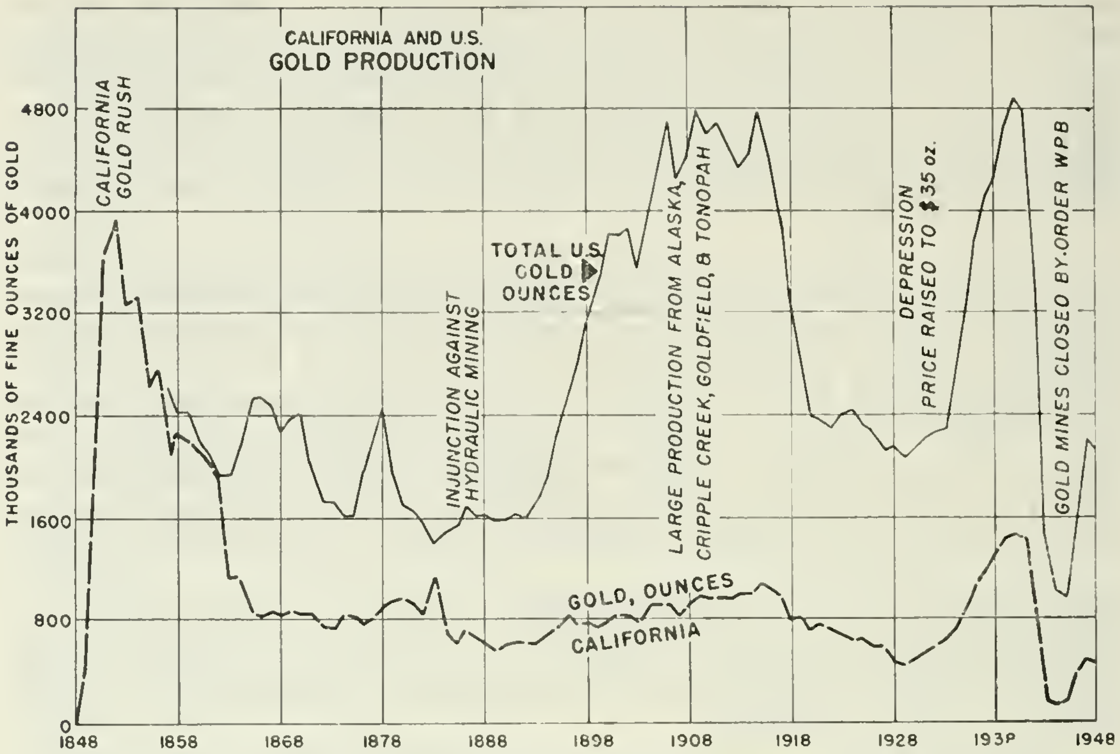

FIGURE 1. Chart showing production of gold in California, 1848-1948, and total United States production, 1857-1948.

History of Production. Gold is believed to have been produced from San Feliciana Canyon in western Los Angeles County prior to 1840,[8] and in 1844 Don Manuel Castanares, deputy for California to the Congress of Mexico, reported that placers near Los Angeles had produced up to December 1843, a total of 2000 ounces of gold dust.[9]

This early work was forgotten in the rush started by Marshall's discovery at Coloma. The large output of gold from surface placers in the first 12 years after 1848 reached a peak of $81,294,700 in 1852. Hydraulic mining and the working of gold-quartz ores did not make large contributions to the gold yield until the late sixties; hydraulic mining ceased to be an important factor after 1888. Drift mining of buried channels partly made up for this loss in the eighties and nineties.

Bucket dredging began to be highly productive about 1903, and has continued so ever since, being the largest source of gold at present.

"Boom" periods are always unfavorable for gold mining, as labor and materials become expensive and the fixed price for gold prevents any increase to cover higher costs of mine operation. For this reason, gold production dropped steadily from 1921-29 inclusive, reaching in 1929 the lowest annual production since 1848. With the onset of the recession in the nineteen-thirties and with the revaluation of gold in 1934, production climbed yearly to a maximum of $50,948,485 in 1940. This climb was stopped by the era of high wages and scarcity of materials and equipment which set in with the beginning of the war in 1941. Further restrictions were placed on the few operators able to continue work by the promulgation of order L-208 by the War Production Board October 8, 1942. This order was lifted July 1, 1945. Gold dredging has

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[8] Ireland, Wm., Jr., Los Angeles County: California Min. Bur. Rept. 8, p. 334, 1888.
[9] Mercantile Trust Review of the Pacific, vol. 11, no. 2, p. 43, Feb. 15, 1925.

been resumed on a scale nearly equal to that before the war, but lode mining has been unable to recover its position because wages increased in the post-war period instead of going down.

Of a total recorded gold production of $2,296,913,366 from 1848 to 1948, inclusive, $1,450,318,726 was produced from placer mining. In 1948, more than two-thirds of the gold produced in the state was from placers, principally those worked by bucket dredges.

Placer-gold deposits left untouched because conditions do not permit hydraulicking or dredging will probably be exploited eventually by mechanical means not at present applied to gold mining. Such gravel deposits are the remains of Tertiary river deposits, notably in Nevada, Placer, Plumas, Sierra, El Dorado, and other counties.

IRON

By James W. Vernon

Iron production in California was relatively small until 1942 when heavy demands were placed on the state's iron deposits by the newly constructed Kaiser Company blast furnaces and steel plant at Fontana. Since then California's iron output has centered about two deposits, first the Vulcan mine in San Bernardino County, and later, the Eagle Mountains mine in Riverside County. Recent expansion of the Fontana plant facilities has placed an increased demand on the Eagle Mountains property, the only current California source of ore for pig iron.

Mineralogy. Magnetite ($FeO \cdot Fe_2O_3$) is the most abundant mineral in California iron ores; but, the proportion of hematite (Fe_2O_3) in some deposits equals or exceeds that of magnetite. Limonite [$FeO(OH) \cdot n(H_2O)$] is present in small quantities in practically all iron deposits of the state. Many minerals typical of contact-metamorphic zones are associated with the ore minerals.

In the United States, production of hematite ore greatly exceeds the combined production of all other iron ores. Magnetite in magmatic segregations is the most important iron ore mineral in Sweden; limonite is an important ore mineral in Spain.

Geologic Occurrence. Although more than 100 iron deposits are known in California, deposits at fewer than 20 localities contain most of the known reserves. During World War II, 13 of the most important iron occurrences in California were studied by the U. S. Geological Survey and the U. S. Bureau of Mines. Results of these investigations, including geologic maps and data obtained by trenching and drilling the deposits, have been published by the California Division of Mines.[1] Nine of these localities contain the principal deposits of an iron-bearing province in Riverside and San Bernardino Counties, southeastern California; two others are in Shasta County, and Sierra and Madera Counties contain one each. The deposits of Riverside, San Bernardino, and Shasta Counties are contact-metamorphic, and represent replacements of carbonate rocks through mineralization genetically related to nearby intrusive rocks. The iron deposits ordinarily are at or near the intrusive contacts. In many places the mineralization was localized by the intrusive contact, but control by faulting and fracturing in the intruded rocks is also common.

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[1] Jenkins, O. P., ed., Iron resources of California: California Div. Mines Bull. 129, 304 pp., 1948.

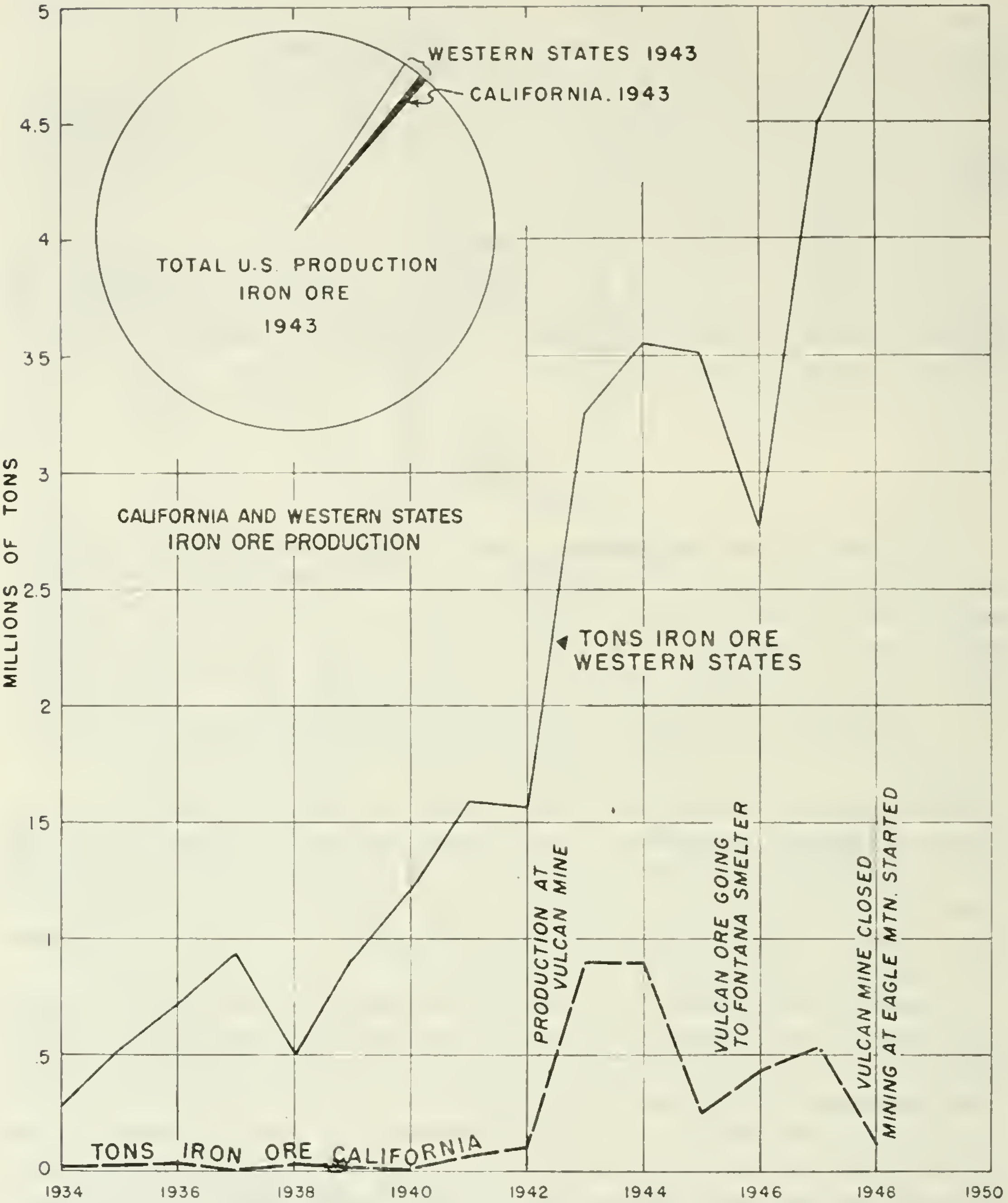

FIGURE 1. Chart showing iron-ore production of California, 1934-48, compared with production of the western states (Arizona, California, Missouri, Nevada, New Mexico, South Dakota, Texas, Utah, Washington, Wyoming).

The Eagle Mountains iron deposits, the largest known in California, are in Riverside County 40 miles east of Indio. They are believed to be replacements of calcareous sediments by magnetite. Five major ore bodies are in a mineralized zone more than 4 miles long and about a quarter of a mile wide. This zone traverses an area of complexly folded and faulted rocks, intruded by sill-like masses of quartz monzonite. Much of the magnetite has been altered to hematite. Oxidation extending to an average depth of 200 feet has generally removed pyrite, which averages about 3 percent in fresh ore. The ore mined for blast-furnace feed has averaged more than 50 percent iron.

The Vulcan mine, which furnished ore for the blast furnace prior to the opening of the Eagle Mountains mine, is 9 miles southeast of

Kelso, San Bernardino County. The deposit is a replacement of limestone near its contact with monzonite. The ore bodies resulted from invasion of limestone by monzonite magma. Mining of this deposit has been discontinued because of increased stripping costs and increased sulfur content with depth.

Other large deposits in San Bernardino County are the Iron Mountain deposits (Lava Beds district) 38 miles southeast of Barstow, the Iron Mountain and Iron King deposits (Silver Lake district) 12 miles west of the town of Silver Lake, the Cave Canyon deposits about half a mile north of Baxter, and the Beck deposits in the Kingston Range in the northeastern part of the county. Surface exposures of these, however, are not as extensive as those at the Eagle Mountains deposit. Other deposits in this province include the Old Dad Mountain deposit, 16 miles southeast of Baker; Iron Hat (Ironclad) deposits, 6 miles north of Cadiz; and the Ship Mountains deposit, 3 miles east of Siam.

In northern California the California, Shasta, and Hirz Mountain iron deposits in Shasta County are geologically similar to the larger iron deposits in southeastern California, being contact-metamorphic replacements of calcareous sediments associated with granitic intrusives.

Iron deposits in Sierra County near Lake Hawley and Spencer Lakes are magnetite replacements of clastic sediments, tuffs, and lamprophyre dikes. The magnetite is probably genetically related to nearby metadiorite intrusions; these deposits have been dynamothermally metamorphosed. The Minarets deposits of Madera County are lenses of magnetite in a sequence of metamorphosed volcanic rocks. Sedimentary and magmatic iron deposits are uncommon in California.

California's iron ore reserves are estimated at 100 to 150 million tons, of which half is considered to be sub-marginal under present economic conditions.[2] The nine largest deposits of southeastern California contain approximately three-fourths of the known reserves. The Eagle Mountains deposits alone contain at least one-third of the total known reserves. These deposits have been estimated to contain 28,000,000 tons of measurable ore assaying 30 percent iron or more; an additional 15,000,000 tons of the same grade is inferred. No other known deposits in California are of comparable size. Ore reserves remaining in the Vulcan deposit are estimated to be in excess of 2,000,000 tons. The seven other deposits in San Bernardino County previously mentioned contain most of the remaining ore reserves of this area.

The Shasta and California deposits in Shasta County are estimated to contain more than 1,000,000 tons of high-grade ore each. The Hirz Mountain deposit in the same area and the deposits of Sierra County are much smaller. Although the Minarets deposit of Madera County is estimated to contain 5,000,000 tons of high-grade ore, it is too inaccessible to be exploited in the foreseeable future.

Utilization.[3] The most extensive use of California's iron ore is in the Fontana blast furnace of the Kaiser Company. Since operations began there January 1, 1943, more than 2,500,000 tons of blast furnace grade ore has been mined by the Kaiser Company at the Vulcan deposit and later at the Eagle Mountains mine. From this ore and from supplementary supplies from Utah, nearly 2,000,000 tons of hot metal has been

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[2] Op. cit., p. 10.

[3] Powell, K. B., Raw materials, Kaiser Company, Inc.: An address presented at the Los Angeles Fall meeting of the Am. Inst. Min. Met. Eng., Oct. 15, 1948.

produced. The Fontana installation is an integrated steel plant. Hot metal is conveyed from the blast furnace to six open-hearth furnaces where it is converted to steel.

Exploitation of the Vulcan iron deposit in San Bernardino County, by the Kaiser Company, to supply the blast furnace at Fontana, began in late 1942 and ended in July 1948 when operations were moved to the Eagle Mountains deposit, Riverside County. To transport ore from the Eagle Mountains mine to Fontana, it was necessary for the Kaiser Company to construct 51 miles of railroad to Ferrum on the Southern Pacific Railroad. Although the current demands will be doubled when the new $17,000,000 blast furnace is functioning, it is expected that the Eagle Mountains mine will supply all the ore required by the Fontana operations.

Western magnetite ore is used for many purposes other than in the production of pig iron. Since before World War I California iron ore has been used intermittently for ship ballast and for heavy aggregate. Small amounts of magnetite sand derived from beach sands at Aptos, Santa Cruz County, and from Hermosa Beach, Los Angeles County, have been used as heavy aggregate. The mining industry uses magnetite as heavy media in sink-float plants, and in the beneficiation of coal. Iron oxides are used as paint pigments and by the chemical industries for many purposes. Cantilever bridge spans are often counterweighted with magnetite. During World War II about 360,000 tons, mostly from Shasta County, were used for ship ballast during the intense shipbuilding activity on the Pacific Coast. Renewed shipbuilding activity on the Pacific Coast would again create a market for ship-ballast magnetite. Magnetite is also suitable as heavy aggregate, and it has been used for temperature control in quick-setting cements used in dam construction. The Cave Canyon deposits, San Bernardino County, have been the chief source of ore for high-iron cement.

Although some new uses are found every year for iron ore and iron and steel, it is expected that the bulk of these materials will continue to be used, as they have been in the past, in the manufacture of machines, tools, and building materials.

Markets. Virtually no open market for iron ore exists in California because captive mines supply most of the demands. Magnetite is intermittently produced for ship ballast and heavy aggregate. Small amounts of iron ore are used in open-hearth furnaces which operate in the state. Potential markets may be found for California iron ore in the Pacific-facing countries, especially Japan. Increased future production of California iron ore may be anticipated as part of the present trend toward western industrialization. An experimental program in progress at the United States Bureau of Mines pilot plant at Shasta Dam may develop new uses for California iron ore, as in ferro-alloys.

Mining Methods. The Eagle Mountains mine of the Kaiser Company is an open-pit operation in which the ore is removed by blasting in a series of 30-foot benches. Broken ore is trucked to a nearby plant for crushing. The crushed ore is conveyed to a stock pile from which it is loaded into railroad cars. Most of the ore from the Vulcan, Cave Canyon, and Shasta County deposits has also been mined by open-pit methods.

History. The following is quoted from a paper by R. F. Helmke:[4]

> "On the West Coast various forges and foundries attempted to meet some of the demand for steel products in the years following the gold rush. In the year 1849, the Union Iron Works of San Francisco ran the first casting ever made in California; and the old Vulcan Iron Works, the Miners' Foundry, and the Pacific Iron Works all sought to meet the pressing need for iron products in the mining areas. The San Saba Mining Company was incorporated to mine Sierra County ores for some of the small blast furnace operations in California which produced iron during this period. The Pacific Rolling Mills of San Francisco was organized in 1868 to produce ship forgings, rails, and a number of other items from local iron, for which iron ore from Sierra and Placer Counties was used. A blast furnace producing 30 tons of pig iron daily, is reported to have operated almost steadily from 1880 to 1885 near Clipper Gap in Placer County, selling its output to railroads for car wheels and axles, and to the foundries and mills on the Coast. Competition from pig iron brought in as ship ballast, as well as depletion of high grade ore, are given as the reasons for closing the plant. * * * During a ten-year period ended with World War I the Noble Electric Steel Company produced a high quality pig iron at Heroult, California, by electric furnace reduction of Shasta iron ore, but cost of electricity was too high to make the operation a success."

LEAD

By Richard M. Stewart

A total of more than 300 million pounds of lead have been obtained from deposits in California. This represents approximately half of one percent of the national total. Since 1942 the state's annual lead output has ranged from 10 to 20 million pounds, and has averaged about 2 percent of the national output. There have been no successful substitutes for lead in most of its wide variety of uses, and in 1948 increased consumer demands raised the price to higher levels than ever before. This brought about increased exploration for and development of lead properties in California and in other states. Lead production in California, which has steadily increased in recent years, showed a slight decrease in 1948. The value of the state's 1948 lead output, however, was greater than the 1945 output. Mines in Inyo County have been the principal lead sources in California; they produced nearly nine-tenths of the state's total production of the metal in 1948.

Mineralogy and Geology. The primary mineral galena (PbS) is the chief source of lead throughout the world, but the secondary minerals, cerussite ($PbCO_3$) and anglesite ($PbSO_4$), are also significant ore minerals in the oxidized zone of some deposits. Other significant, though less abundant, oxidized lead minerals include linarite, a basic sulfate of lead and copper; plumbojarosite [$PbFe_6(OH)_{12}(SO_4)_4$]; pyromorphite ($Pb_5P_3O_{12}Cl$); and wulfenite ($PbMoO_4$). The world-wide tendency for zinc and silver minerals to accompany those of lead also applies to most lead deposits in California.[1] Primary lead-zinc deposits typically occur as cavity fillings or replacement bodies; most have formed in limestone or dolomite. Some lead-zinc deposits, particularly those in veins, are associated with intrusive igneous rocks. Many replacement bodies, however, do not clearly show this relationship.

In the oxidized zone galena is first altered to anglesite; the anglesite, in turn, alters to cerussite. Lead ore thus oxidized is the most resistant

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[4] Helmke, R. F., Recent developments in the western iron industry: An address presented at the National Convention of the Am. Inst. Min. Met. Eng., San Francisco, Feb. 15, 1949.

[1] See sections on silver and zinc in this bulletin.

of the base-metal ores, as both anglesite and cerussite are relatively insoluble. Under particularly favorable oxidizing conditions, lead minerals will leach slightly, but not enough to appreciably affect the grade of the ore for more than a few feet beneath the earth's surface. At the lead mines currently operating in the desert regions of California the water table lies beneath the lowest levels, and most mining has been in oxidized ore.

Localities. Most of the lead produced in California has been obtained from three districts, each of which is in Inyo County. These are (1) the Cerro Gordo district about 13 miles due east of Lone Pine, and near the crest of the Inyo Range; (2) the Darwin district about 35 miles southeast of Lone Pine; and (3) the Tecopa district at the southern end of the Nopah Range in the southeastern corner of Inyo County.

The Cerro Gordo district has the largest total output, but has not produced lead in quantity since 1877. Here the ore [2] is in lenticular bodies composed of argentiferous galena, cerussite, anglesite, smithsonite, sphalerite, tetrahedrite, and pyrite. These are mesothermal deposits which have replaced Devonian marble along fissures and which also have been controlled by bedding in a Devonian quartzite.[3] Much of the zinc in the lead-rich ore bodies has been removed in solution and has been redeposited as secondary bodies beneath those of the lead. This zinc ore was mined separately from 1911-15.

The ore bodies of the Darwin district,[4] which in recent years have been the principal source of lead in California, consist mainly of argentiferous galena. They also contain lesser amounts of sphalerite and chalcopyrite, and minor amounts of luzonite and tennantite. Extensive near-surface oxidization has produced a gossan composed mostly of cerussite and containing smaller quantities of anglesite, smithsonite, malachite, and chrysocolla. Residual enrichment of the gossan was effected by the leaching of zinc, sulfur, and iron.

The ore bodies occur in Pennsylvanian limestone which has been silicated in a wide zone peripheral to a quartz diorite stock. Mineralization is mesothermal and has been guided by igneous contacts, bedding planes and cross-fractures.

The ore bodies of the Tecopa district consist mostly of lead carbonate with subordinate galena. These have formed as irregular lenses along a gently dipping fault plane in the Cambrian (?) Noonday dolomite.

Other areas in Inyo County which in recent years have contributed appreciable quantities of lead include the Modoc district at the northeast corner of the Argus Range; the Slate Range district east of Trona; the Ubehebe district in the northern Panamint Range; and the Union district on the east side of Owens Valley.

Most of the lead that has not come from deposits of Inyo County has been a by-product of the copper and gold mines of the Sierran foothill and Klamath Mountains areas.[5] Other areas which have produced

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[2] Knopf, A., A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 110, pp. 106-118, 1918.

Tucker, W. B., and Sampson, R. J., Mineral resources of Inyo County: California Div. Mines Rept. 34, pp. 426, 427, 431-434, 1938.

[3] Merriam, C. W., Geology of the Cerro Gordon mine area, Inyo County, California (abstract): Econ. Geology, vol. 44, p. 82, 1949.

[4] Kelly, V. C., Geology of the ore deposits of the Darwin silver-lead mining district, Inyo County, California: California Div. Mines Rept. 34, pp. 503, 562, 1938.

Davis, D. L., and Peterson, E. C., Anaconda's operation at Darwin mines, Inyo County, California: Am. Inst. Min. Met. Eng. Tech. Pub. 2407, July 1948.

[5] See sections on copper and gold in this bulletin.

lead recently include the Clark Mountain district in northeastern San Bernardino County and the Santa Rosa district in Orange County.

Utilization.[6] Lead was probably one of the first metals to be won from its ores by smelting. Effectively used by Roman artisans for water pipes, it has served an increasing variety of purposes. The properties of lead which make it most useful are extreme resistance to corrosion, relatively high density, ease of fabrication and ready weldability, and a combination of low smelting point and high boiling point. In 1948 approximately 30 percent of the lead consumed in the United States was used in the manufacture of storage batteries, 15 percent in cable covering, 10 percent in paint pigments and 8 percent in tetraethyl lead fluid.

Lead is more frequently alloyed with antimony than any other metal. The proportion of antimony in such alloys ranges from a mere trace to 25 percent. This hardens the lead, so that it resists abrasion and mechanical injuries in such uses as cable covering, pipe and sheet lead, bearing metal, and grids for storage batteries. Lead-antimony-tin alloys are used in type metals. In such metals the addition of tin adds to the ease of casting at low temperature. Calcium added to lead produces an age-hardening alloy, and lead-tellurium alloys can be work-hardened to a greater extent than any other lead alloys.

The use of lead pigments remains fairly constant, and has not reflected the increased consumption of all pigments in the paint industry. Lithopone and titanium oxides have been increasingly used as substitutes for basic lead carbonates as white hiding pigments. The synthetic iron oxides are being used in place of litharge and red lead as hiding pigments. Substitutes have also been found in a few minor uses of lead, but none have been found for the uses that consume the bulk of lead production.

Lead is used as a shielding material in nuclear fission processes, and in glass from which television tubes are manufactured. Some of the latter contain as much as 30 percent lead, in the form of lead oxide.

Because lead is extremely resistant to corrosion, much of it can be recovered and reused. Lead in such products as paints and ethyl gasoline, however, is not recoverable. Of the total national annual lead consumption, approximately 45 percent is ultimately reclaimed. The national production of reclaimed lead in 1948 was greater than 500,000 tons, and, for the third successive year, surpassed the amount obtained from mines.

Markets.[7] California's lead production for 1948, which amounted to 9,110 short tons, came principally from the Darwin district. This total was less than the 10,080 tons produced in 1947.

The total United States lead production in 1948 was 386,932 short tons.[8] This is estimated by the Bureau of Mines to represent 57 percent of the 1948 industrial consumption. Even though California contributes but a small percentage to the total United States production, it still ranks among the first 10 producing areas, since southeastern Missouri and the Rocky Mountain regions together produce more than two-thirds of the total. In 1946 California ranked eighth.

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[6] Betterton, J. O., Lead, in Mathewson, C. H., and others, Modern uses of nonferrous metals, pp. 150-169, Am. Inst. Min. Met. Eng., 1935.
Ziegfeld, R. L., Eng. and Min. Jour., vol. 150, no. 2, pp. 77-79, Feb. 1949.

[7] Bramel, H. R., The marketing and metallurgy of complex ores in California, in Copper in California: California Div. Mines Bull. 144, pp. 161-197, 1948.

[8] Mote, R. H., Lead industry in 1948—preliminary: U. S. Bur. Mines Mineral Industry Survey, Mineral Market Report mms. 1710, April 1949.

FIGURE 1. Chart showing amount and value of lead produced in California, 1894-1948.

Most of the California lead ores and concentrates are shipped out of the state, rather than to the smelter at Selby, Contra Costa County, for smelting and refining. The Selby smelter, however, provides California consumers with refined lead in quantity, derived largely from imported ores.

The accepted prices for lead are those of the New York City area which is the principal United States market center for refined metals. Lead is marketed in four principal grades: corroding, chemical, common, and antimonial. However, the price quoted is that for common lead. Prices in the other major market center, East St. Louis, are lower by approximately the freight difference between the two centers.

During 1948, consumer demand for lead remained high because of the threat of shortages from various causes, including government stock piling. This resulted in three price advances to establish record highs. The price jumped from 15 cents per pound to 17½ cents, then 19½ cents, and finally 21½ cents per pound.

Mining Methods and Treatment.[9] Lead ores in California are mined by normal underground mining methods, as contrasted with some of the very large-scale room-and-pillar methods used in the disseminated lead deposits of southeastern Missouri. The shipping product is either the raw ore or a concentrate.

Lead is obtained from the ore by roasting and reduction methods in blast and reverberatory furnaces. The method which is used most is reduction by carbon in a blast furnace after the ore has been roasted and sintered. Recovery of lead as base bullion is high, being up to 95 percent of the lead in the blast-furnace charge. This base bullion is refined, and the precious metals are recovered by pyrometallurgical, electrolytic, or a combined method.

History of Production.[10] The first lead mined in California is believed to have been obtained previous to 1859 by Mormons who worked silver deposits in the southern part of the Panamint Range of Inyo County.

The Cerro Gordo district was discovered between 1862 and 1866, and the deposits were first worked by Mexicans on a small scale. In 1869 American interests took over, and subsequently two smelters were erected at Cerro Gordo and a third on the shore of Owens Lake. In 1876 two of the mines, the Santa Maria and the Union, were consolidated into the Cerro Gordo mine. Activity declined, and ceased in 1877, when the richer ores were worked out.

In the early eighties, the railroad was completed to Keeler, and interest was revived; the mines have been worked intermittently to the present. During the period 1911-15, rich zinc ore bodies were worked. The district is credited with a total production of lead, silver, and zinc in excess of $17,000,000.

Deposits in the Darwin district were discovered in the early seventies, and the district flourished during the mining of the rich oxidized lead-silver ores. Before 1880, several mills and smelters were in operation, and the town of Darwin, named for Dr. Darwin French, had a population of about 5000 persons. Water was piped into the district from the

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[9] Bowman, R. G., Lead, in Liddell, D. M., and others, Handbook of non-ferrous metallurgy, 2d ed., vol. 2, pp. 145-215, 1945.

[10] Kelley, V. C., op. cit.
Knopf, A., op. cit.
Tucker, W. B., and Sampson, R. J., op. cit.

Coso Mountains. Exhaustion of the surface ores, the isolated location of the district, and unfavorable price fluctuation allowed only intermittent operation until World War I. Mining was suspended during the period, and was resumed prior to World War II.

In 1945 the Anaconda Copper Mining Company purchased the major producing properties. The Darwin district had produced nearly $7,000,000 in lead, silver, and zinc prior to 1945, nearly half of which was produced before 1900.

MANGANESE

By Richard A. Crippen, Jr.

Manganese mineralization is widespread in California. Approximately 675 deposits in 44 counties have been mined or prospected. Of these, about one-fourth have recorded productions.[1] Since 1867, when manganese was first mined in California, deposits in the state have yielded about 168,000 tons of ore containing approximately 45 percent manganese. Nearly nine-tenths of this output was obtained during World Wars I and II when prices were higher and grade requirements lower than in peacetime. In 1944 an all-time peak production of 30,263 tons of manganese ore was reported in California.

The United States is almost entirely dependent on foreign sources for its manganese supply. Since 1940 a yearly average of 1½ million tons of manganese ore has been consumed domestically, chiefly in the production of steel. At the end of World War II many domestic manganese mines were unable to compete successfully with foreign sources; and in the period 1944-48 the United States output of manganese ore dropped from approximately 240,000 to 130,000 tons per year. In 1947 and 1948 the production of manganese in California was negligible. Many of the higher-grade ore bodies in the state have been worked out and much of the known remaining ore does not meet present metallurgical specifications. But if operators could meet foreign competition and if ore of lower grade again became acceptable, manganese mining in California would undoubtedly revive.

Mineralogy and Geologic Occurrence. Manganese, in small amounts, is a primary constituent of all igneous rocks. Commercial contrations of manganese occur in open-space fillings and replacement deposits; but most of the world's manganese is obtained from sedimentary deposits. Deposits of all of these types commonly have been metamorphosed.

Most of the world's manganese ores are composed chiefly of oxides. Pyrolusite (MnO_2), psilomelane (a barium-bearing, hydrous manganese oxide), and wad (an impure mixture of manganese oxides) are the most common oxides; the oxides manganite ($Mn_2O_3 \cdot H_2O$), braunite ($3MnMnO_3 \cdot MnSiO_3$), and hausmannite (Mn_3O_4) are also ore minerals, but are less common.

Pyrolusite is apparently always of secondary origin; psilomelane is nearly always of secondary origin, but is locally a hydrothermal mineral. Wad is commonly a secondary product, but also forms as a direct chemical or biogenic precipitate. Manganite occurs in low-temperature

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[1] Jenkins, O. P., Outline geologic map of California showing locations of manganese properties; Economic mineral map of California no. 5—manganese, California Div. Mines, 1943.

hydrothermal veins and in deposits formed by meteoric waters. Hausmannite is generally a high-temperature hydrothermal vein mineral.

Rhodochrosite ($MnCO_3$), the only other manganese mineral of commercial significance, is generally accompanied, in isomorphous relationship, by carbonates of iron, magnesium, and calcium. Rhodochrosite is common in hydrothermal and metamorphosed deposits and as one of the original precipitates in sedimentary deposits.

Rhodonite ($MnSiO_3$) is a prominent mineral in many hydrothermal or metamorphosed manganese deposits. It is not ordinarily a commercial source of manganese, but some oxidized ores of rhodonite are worked. To a limited extent, it is used as an ornamental stone or semiprecious gem. Hydrous manganese silicates (mostly bementite) are common as primary minerals in many sedimentary deposits in California. Spessartite (manganese garnet) is common in metamorphosed manganese deposits.

Alabandite (MnS) is known only as a vein mineral and is very rare in California.

The geological processes involved in the deposition of sedimentary manganese have been discussed by Hewett; [2] the occurrence and minerals of manganese have been reviewed by Crook.[3]

The manganese in most sedimentary deposits is believed to have been leached from pre-existing manganese minerals, transported by ground water, and redeposited as carbonates or oxides in bogs, lakes, or seas. Other sedimentary deposits, including most of those in California, have apparently obtained manganese from waters of igneous origin. This manganese is precipitated in surface waters as carbonates, silicates, or manganiferous opal.

The origin and distribution of manganese in California has been described in detail in two volumes published by the California Division of Mines [4] and the following data have been abstracted largely from these sources.

Most of the commercial concentrations of manganese in California are of sedimentary origin, but a large proportion of these have been subsequently metamorphosed. Manganese in the state has also been produced from fissure and replacement deposits of hydrothermal origin. Miscellaneous manganese occurrences in California include large, low-grade, bedded wad deposits; fanglomerate which is cemented by manganese oxide adjacent to fissures; various superficial deposits; and manganiferous iron ore.

Most of the unmetamorphosed sedimentary manganese deposits of California are found in chert of the Franciscan (Upper Jurassic) formation which is widely exposed in the Coast Ranges. Their general features are similar and they are known collectively as deposits of the "Franciscan type."

Franciscan chert is ordinarily thinly layered and has shaly partings, but it locally forms large massive lenses. It is in these lenses that

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[2] Hewett, D. F., Manganese in sediments, in Twenhofel, W. H., and others, Treatise on sedimentation, 2d ed., pp. 571-576, 1932.

[3] Crook, T. H., Occurrence and minerals of manganese: California Div. Mines Bull. 125, pp. 23-40, 1943.

[4] Jenkins, O. P., ed., Manganese in California including outline geologic map of California showing locations of manganese properties: California Div. Mines Bull. 125, 387 pp., 1943.

Trask, P. D., and others, Geologic description of the manganese deposits of California: California Div. Mines Bull. 152, 909 pp., 1950.

manganese concentrations commonly occur; some deposits are in red chert but most of the larger bodies have country rock of white, greenish, or buff chert. The ore bodies generally resemble elliptical pancakes in shape, and most are less than 200 feet in maximum diameter. The largest ore body of this type in California, that at the Ladd mine in San Joaquin County, is 800 feet long.

The larger bodies generally contain massive ore which grades into disseminated ore near the edges. Rhodochrosite and manganese silicate (bementite?) are the principal primary minerals. Oxidation of these minerals to "black oxide" ore ranges in depth from 10 to as much as 200 feet.

It is believed that the Franciscan ore bodies and the associated chert were deposited in ocean basins of restricted circulation. Although the source of the silica and manganese has been a matter of dispute, the workers whose studies have been the most comprehensive[5] favor the concept that silica, manganese, and iron were precipitated simultaneously, and that they are of submarine volcanic origin.

Metamorphosed sedimentary manganese deposits are widespread throughout the Sierra Nevada,[6] and are confined to rocks of the Calaveras (Paleozoic) and Amador (Jurassic) groups. Some deposits of this area have undergone only moderate dynamic metamorphism; others, which occur as roof pendants in granodiorites, have been intensely metamorphosed.

Previous to metamorphism, these deposits were nearly identical with the manganese deposits of the Coast Ranges. During metamorphism the manganese carbonate has merely recrystallized; siliceous manganiferous substances have formed rhodonite and spessartite. The depth of oxidation is generally very shallow and most of the deposits are of little economic importance.

At numerous localities in the desert regions of southeastern California ore shoots of manganese oxides have formed in brecciated rocks adjacent to fissures. Only a few, however, have production histories.

> "These shoots range from a few feet to 500 feet in length and from a few inches to 10 feet in width. The general depth of mineralization is unknown. In some places it goes as deep as 100 feet, in others less than 10 feet. The ore consists principally of hard manganese oxide, similar to psilomelane, but soft oxide and a radiating mineral reported to be manganite are present. Many of the deposits contain veins of white calcite which are clearly later than the manganese. The average manganese content of the deposits mined is from 15 to 30 percent. The hard oxide can be hand-sorted in some places to give a product containing 40 to 45 percent of manganese."[7]

The host rocks for these deposits include volcanic rock, fanglomerate, granite, and limestone.

Manganese in California also occurs in large low-grade bedded deposits, in replacement deposits, in manganiferous iron deposits, and in superficial deposits of several types; but most of these are too small or too low grade to be of commercial importance.

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[5] Taliaferro, N. L., and Hudson, F. S., Genesis of the manganese deposits of the Coast Ranges of California: California Div. Mines Bull. 125, pp. 217-275, 1943.

[6] Taliaferro, N. L., Manganese deposits of the Sierra Nevada, their genesis and metamorphism: California Div. Mines Bull. 125, pp. 277-332, 1943.

[7] Trask, P. D., Wilson, I. F., and Simons, F. S., Manganese deposits of California, a summary report, in Manganese in California: California Div. Mines Bull. 125, p. 61, 1943.

Localities. Of the 675 manganese-bearing localities described in California Division of Mines Bulletin 152, production has been recorded from about 170. Approximately 80 percent of the manganese produced in California has been obtained from deposits in the Coast Ranges. These are grouped largely in four areas: (1) the Mad River Valley in western Trinity County; (2) east-central Mendocino County and the adjoining part of Lake County; (3) the mountains southwest and south of Tracy in San Joaquin, Alameda, Santa Clara, and Stanislaus Counties; and (4) the western part of San Luis Obispo County.[8]

Previous to 1943, thirteen mines in these areas had each produced more than 1,000 tons of manganese ore. The mines in the area south and southeast of Tracy, of which the Ladd and the Buckeye are by far the largest, have yielded approximately 63,000 tons of ore. This is about one-third of the total output for the state. The Camp 9, Fabian, Cummings, and Liberty mines have also contributed substantially to the output of the district.

The Blue Jay mine, which since its discovery early in World War II has yielded nearly 5,000 tons of manganese ore, has been the largest producer in the Trinity County area.

In east central Mendocino County the manganese production has come largely from three mines. The Foster Mountain mine has yielded approximately 6,000 tons of ore; the Thomas mine about 4,700 tons, and the South Thomas mine about 1,500 tons.

In San Luis Obispo County the Staneuch and Welch mines have the largest productions.

During World War I approximately 1,000 tons of manganese ore were mined on claims of the Shasta Copper Company near Heroult. Here "a siliceous porphyry adjacent to a fissure zone has been replaced by red jasper and by manganese oxides, forming a low grade deposit that contains from 15 to 20 percent of manganese. . . . The ore was high in silica and was used for making silico-manganese."[9]

The principal manganese-producing areas in the desert regions of southeastern California have been the Owls Hole district in north-central San Bernardino County; the Ironwood and Little Maria Mountains districts in eastern Riverside County; and the Paymaster district[10] in eastern Imperial County.

Though manganese does occur in the California deserts in extensive low-grade deposits that may be sedimentary in origin, the commercial manganese in these areas has been obtained from fissure deposits. The combined total production of these deposits has been about 35,000 tons.

Utilization. In 1947 more than 95 percent of the manganese consumed in the United States was used in steel making.[11] Most of the manganese used for this purpose is first converted into the alloy ferromanganese (78 to 82 percent manganese, 8 to 15 percent iron, 0.5 to 1 percent silicon, 5 to 7 percent carbon, and minor amounts of phosphorus and sulfur). Lower-grade manganese alloys, spiegeleisen (18 to 22 percent

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[8] Jenkins, O. P., Outline geologic map of California showing locations of manganese properties; Economic mineral map of California no. 5—manganese, California Div. Mines, 1943.

[9] Trask, P. D., Wilson, I. F., and Simons, F. S., op. cit.

[10] Hadley, J. B., Manganese deposits of the Paymaster mining district, Imperial County, California: U. S. Geol. Survey Bull. 931-S, pp. 459-473, 1942.

[11] Melcher, N. B., Manganese: Minerals Yearbook 1947, p. 755, 1949.

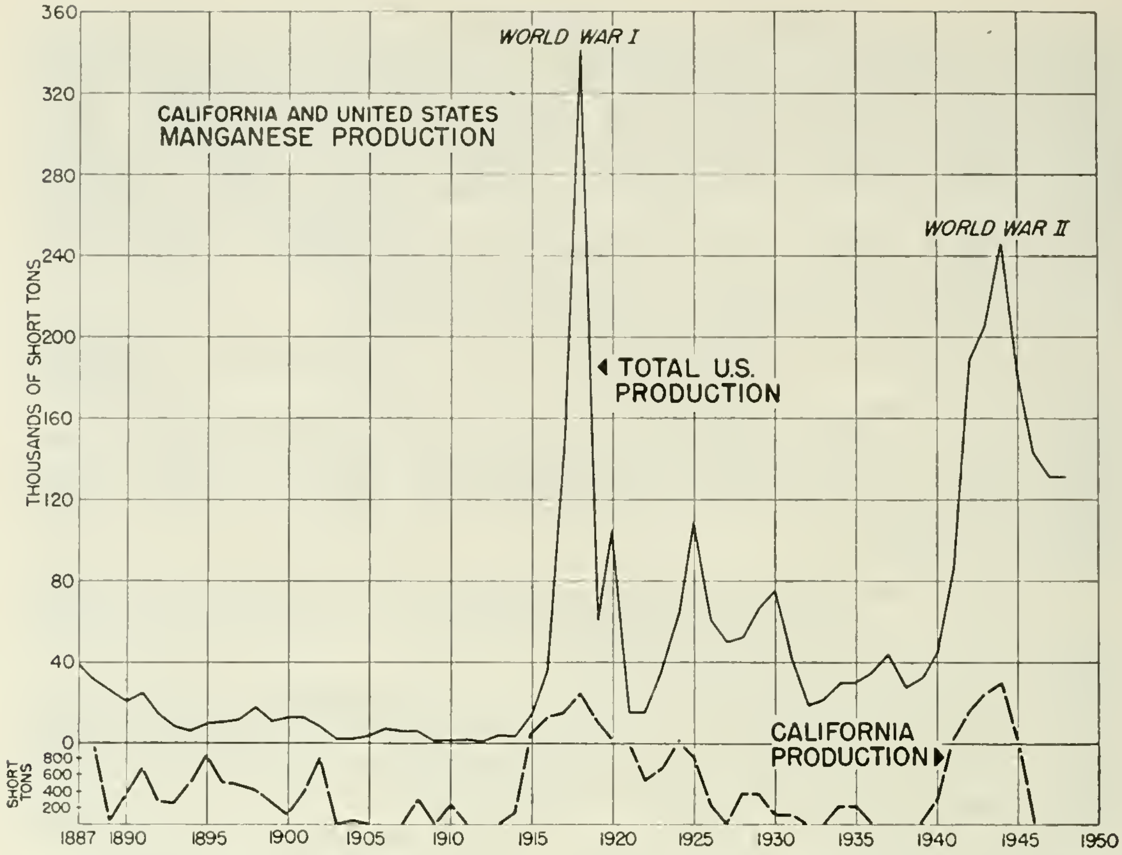

FIGURE 1. Chart showing production of manganese in California, 1888-1946, and in the United States, 1887-1948.

manganese, 70 to 80 percent iron, and 5 to 6 percent carbon) and silicon-manganese (65 to 70 percent manganese, 12 to 25 percent silicon, and the remainder iron and carbon) are also commonly used but less extensively.

These alloys, especially ferromanganese, are essential to the steel industry. In small amounts the manganese purifies the steel by uniting with oxygen and sulfur and passing into the slag. In larger amounts the alloys, in addition, increase the strength and hardness of steel and impart properties that allow it to be more easily rolled and forged.[12] The manganese consumed in the steel industry averages about 14 pounds per ton of steel.

Manganese is also used in the manufacture of dry batteries and in innumerable chemical compounds which are used principally in photographic compounds, in varnish and paint dryers, in fertilizers and as coloring agents.

Markets. Since 1945 manganese mining operations in California have been inactive, but in 1948 and early 1949, the domestic consumption of manganese exceeded the combined imports and domestic production. Withdrawals from reserve stocks met the shortage, but prices have risen. This condition is believed to be temporary, however, as increased shipments from foreign sources are expected within 2 years. Import duty was cut in half to a quarter of a cent per pound of contained manganese in 1948.

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[12] The manufacture and applications of ferro-alloys are discussed more fully in a separate section in this volume.

Mining and Treatment. Conventional mining by drift and stope has been the practice in the larger California manganese mines of the Coast Ranges. Many small deposits of oxide ore have been worked by open cut.

Attempts at the beneficiation of low-grade California manganese ores were begun soon after World War I. Methods employing chemical extraction and by electromagnetic separation were used, but were not commercially successful. In later years improved methods have been applied to large low-grade deposits in other states. Most of the manganese ore being produced in the United States is now beneficiated in some manner. The methods used include concentration by flotation, sink and float, or by mechanical and gravity separation devices. Both oxide and carbonate ores are now beneficiated successfully by flotation. The product is nodulized by sintering in rotary kilns. In this process the carbonate is oxidized and thus fitted for metallurgical use.

Electrolytic manganese is produced by electrolysis of solutions of the ore in sulfuric acid. During World War II a commercially feasible electrolytic process was developed by the United States Bureau of Mines and put in pilot plant operation at Boulder City, Nevada. Low-grade ore, averaging 20 percent manganese, was utilized from several western states, including ore from the Ladd mine in San Joaquin County. By May, 1946, when the plant ceased operation, nearly 1½ million pounds of electrolytic manganese had been produced.[13] Another plant, designed by the United States Bureau of Mines was set up at Knoxville, Tennessee, in 1939. Improvements in the process for larger scale production were made by the private operating company, the Electro-Manganese Corporation. With a planned capacity of 450,000 pounds a month, actual production reached 4½ million pounds for the year 1948.[14]

History of Production. Red Rock Island, lying between Richmond and San Quentin in San Francisco Bay, was the source of the first shipment of manganese ore from California in 1866, but the 200 tons sent to New York failed to pay expenses.

In the next year, 1867, the Ladd mine commenced shipment of ore to England. During the following 7 years, over 5,000 tons were shipped and used mostly in manufacture of chlorine gas. This was an old process in which the manganese oxide liberated chlorine from hydrochloric acid. Shipments ceased in 1875 and the reduced production of the mine was diverted to California consumers for smelter flux, and chemical use.

The yearly tonnage of manganese ore fluctuated between zero and 1,500 tons during the period from 1888 until the beginning of World War I. Over 70,000 tons came from California mines during 1915-19, inclusive; but from 1919-41 little was mined. World War II (1941-45, inclusive) caused renewed activity with production of 78,794 tons.

The value of manganese in steel making was first recognized by a worker in a steel plant in India between 1820 and 1840, and he took the process to England, where it was adopted by Bessemer. Less than 1 percent manganese was contained in steel of this period as the effect of greater amounts (10 to 15 percent) was not learned until 1882.

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[13] Melcher, N. B., Manganese: Minerals Yearbook 1946, p. 706, 1948.

[14] Eng. and Min. Jour., vol. 150, no. 7, p. 128, July 1949.

MERCURY [*]

By Richard A. Crippen, Jr.

Over the 100-year period of 1850 to 1949 approximately 89 percent of the nation's mercury [1] output has been obtained from deposits in California. To date nearly 2⅔ million flasks valued at approximately $150,000,000 have been produced in the state. This value is exceeded only by those of gold and copper among the state's metallic mineral commodities. During World War II over 70 percent of the domestic mercury production was from California sources which in the period 1942-45 contributed 113,195 flasks valued at $17,607,320. The 33,948 flasks that were produced in 1943 represented the highest annual output since 1895. But in the years following 1943, mercury production has dropped sharply, a decline caused largely by the difficulty domestic operators have had in meeting competition from imported mercury.

Most of the early production of mercury in California was used in the amalgamation of gold, but in later years it has found greatest use in the manufacture of chemicals and in industrial and scientific instruments.

Mineralogy and Geologic Occurrence. Cinnabar (HgS) is by far the most important ore mineral of mercury, but native mercury and metacinnabarite (HgS) also occur in economic quantities. More than 20 other minerals also contain mercury in their chemical composition. Of these, amalgam (Ag,Hg), tiemannite ($HgSe$), coloradoite ($HgTe$), calomel ($HgCl$), eglestonite (Hg_4Cl_2O), and montroydite (HgO), have been noted in California.

Cinnabar is recognized by its red color, high specific gravity, and adamantine luster. Native mercury, a silver-colored liquid, has been found in vugs in many California cinnabar deposits. Metacinnabarite, a black mercuric sulfide, is less abundant.

Mercury deposits throughout the world are largely confined to regions of Tertiary or Recent volcanic activity. As the quicksilver mineralization is of relatively low temperature, and few commercial bodies exceed 2,000 feet in depth, the deposits are classed as epithermal. Mercury deposits have undoubtedly formed throughout geologic time but because of their shallowness, the earlier ones are likely to have been removed by erosion.

Most mercury ore bodies are irregular and occur in highly fractured zones in many types of rocks. Others, such as those at Terlingua, Texas, have replaced limestones; still others have been deposited at the surface by hot springs.

Mercury deposits contain but few other metallic minerals. Pyrite is generally present and stibnite is locally abundant. The principal gangue minerals are quartz, opal, chalcedony, calcite, dolomite, and barite.

Most of the mercury deposits of California occur in serpentine or in the sedimentary rocks of the Franciscan group (Upper Jurassic) with which the serpentine is associated. Ores are also found in the Knox-

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[*] Much of the material contained in this section has been obtained from the following map and its accompanying text: Jenkins, O. P., and Ransome, A. L., Outline geologic map of California showing location of quicksilver properties; Economic mineral map of California no. 1—quicksilver, California Div. Mines, 1939.

[1] Although "quicksilver" is the term commonly employed in the mining industry and in geologic reports, its synonym "mercury" is preferred in chemical descriptions and is used in statistical summaries by the U. S. Bureau of Mines.

ville (Upper Jurassic) sediments and in overlying Lower Cretaceous sediments and Tertiary volcanic rocks. Relatively small amounts of cinnabar have been obtained from hot spring deposits in the state and small amounts of placer cinnabar have also been mined.[2] The high degree of fracturing in the Franciscan sediments and in the serpentine has favored deposition in these rocks. In general the mercury minerals have formed in the interstices of porous or brecciated rocks. In many places the ore is especially rich beneath such impervious material as fault-gouge, clay shale, or dense volcanic rock. In some deposits the mercury minerals are associated with the so-called "quicksilver rock" or "silica-carbonate" rock. This rock is an alteration product of serpentine and is composed largely of chalcedony, quartz, and carbonate material. The rock is much more widespread than the mercury mineralization and cannot be used as a reliable prospecting guide.

Localities. Twenty-five of the 27 mines that have been the most consistent mercury producers in California are in the Coast Ranges and are, in general, confined to areas underlain by rocks of the Franciscan group and associated serpentine. Within this province are 23 mercury districts which are scattered along a 350-mile belt extending from central Lake County southeastward to southeastern Santa Barbara County. Two of these, the New Almaden and New Idria districts, have been the principal mercury sources in North America.

Other Coast Ranges areas that contain mercury mines with appreciable outputs are, from north to south, the Clear Lake, Mayacmas, Sulphur Creek, Knoxville, Oat Hill, Guerneville, and Vallejo districts in the counties north of San Francisco Bay; the Mount Diablo district in Contra Costa County; the Stayton district in San Benito, Merced, and Santa Clara Counties; and the Adelaida, Oceanic, and Rinconada districts in San Luis Obispo County. Other Coast Ranges mercury districts with relatively small outputs are the Oakville district of Napa and Sonoma Counties; the Phoenix and Orestimba districts in Stanislaus County; the central San Benito district, San Benito County; the Parkfield district in Kings and Monterey Counties; the San Carpojaro district in Monterey and San Luis Obispo Counties; the Pine Mountain district in San Luis Obispo County; and the Cachuma and Los Prietos districts in Santa Barbara County.

Two of the state's 27 principal mercury mines are in districts outside the Coast Ranges province. These are the Altoona mine in the Altoona district of northeastern Trinity County, and the Walibu (Cuddeback) mine in the Tehachapi district of Kern County. Relatively small amounts of quicksilver have also been obtained from the Diamond Creek district of northern Del Norte County; the Beaver Creek district of northern Siskiyou County; the Coso district of southwestern Inyo County; and the Tustin district of Orange County.

The New Almaden mine a few miles south of San Jose in Santa Clara County has produced over 1,000,000 flasks of mercury valued at over 60 million dollars. This represents about one-third of the entire United States production,[3] and its value is more than that of the output of any other metal mine in California.

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[2] Bailey, E. H., and Everhart, D. L., Almaden placer yields cinnabar-rich gravels: Eng. and Min. Jour., vol. 148, no. 6, pp. 77-79, June 1947.

[3] Bailey, E. H., The New Almaden quicksilver mines: California Div. Mines Bull. 154, in press.

The New Almaden ore bodies contain cinnabar as the only mineral of real economic importance. They have formed chiefly by the replacement of silica-carbonate rock along steeply dipping fractures, and are the richest near contacts between the silica-carbonate rock and rocks of the Franciscan group. The largest ore body that has been mined extended down dip for about 1,500 feet. Cobbed ores obtained during the first 15 years of recorded production averaged more than 20 percent mercury. The ore obtained during the entire productive history of the mine averaged slightly less than 4 percent mercury.

The New Idria mine[4] in the southeastern corner of San Benito County, is second only to the New Almaden mine among quicksilver deposits of North America. During the period 1858 to 1948 the mine produced approximately half a million flasks with a total value of about 30 million dollars.

In the New Idria area sediments of the Franciscan group and the Panoche (Upper Cretaceous) and later formations are in fault contact with a dome-like serpentine mass. Cinnabar, the predominant mercury mineral, has been deposited in veins and stockworks in altered and fractured rocks. The ore bodies of greatest commercial importance are in hydrothermally indurated beds of the Panoche formation. Others occur in silica-carbonate rock.

The other mines of the Coast Ranges are too numerous to be included in this brief discussion. An extensive pre-1939, bibliography on California mercury deposits has been provided by Ransome and Kellogg[5] in a paper which summarizes the salient features of most of the mines. During World War II many of the state's mercury-bearing areas were studied in detail by members of the U. S. Geological Survey. In recent years reports of these investigation have been published.[6] Though the Coast Ranges mer-

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[4] Eckel, E. B., and Myers, W. B., Quicksilver deposits of the New Idria district, San Benito and Fresno Counties, California: California Div. Mines Rept. 42, pp. 81-124, 1946.

[5] Ransome, A. L., and Kellogg, J. L., Quicksilver resources of California: California Div. Mines Rept. 35, pp. 353-486, 1939.

[6] Averitt, P., Quicksilver deposits of the Knoxville district, Napa, Yolo, and Lake Counties, California: California Div. Mines Rept. 41, pp. 65-89, 1945.

Bailey, E. H., and Myers, W. B., Quicksilver and antimony deposits of the Stayton district: U. S. Geol. Survey Bull. 931-Q, pp. 405-434, 1942. . . . . California Div. Mines Bull. 147, pp. 37-56, October 1949.

Bailey, E. H., Quicksilver deposits of the Parkfield district, California: U. S. Geol. Survey Bull. 936-F, pp. 143-169, 1942.

Bailey, E. H., Quicksilver deposits of the western Mayacmas district, Sonoma County, California: California Div. Mines Rept. 42, pp. 199-230, 1946.

Eckel, E. B., Yates, R. G., and Granger, A. E., Quicksilver deposits in San Luis Obispo County and southwestern Monterey County, California: U. S. Geol. Survey Bull. 922-R, pp. 515-580, 1941.

Eckel, E. B., Quicksilver deposits of the New Idria district, San Benito and Fresno Counties, California: California Div. Mines Rept. 42, pp. 81-124, 1946.

Everhart, D. L., Quicksilver deposits at the Sulphur Bank mine, Lake County, California: California Div. Mines Rept. 42, pp. 125-153, 1946.

Fix, P. F., and Swinney, M. C., Quicksilver deposits of the Oakville district, Napa County, California: California Jour. Mines and Geology, vol. 45, pp. 31-46, 1949.

Hawkes, H. E., Jr., Wells, F. G., and Wheeler, D. P., Jr., Chromite and quicksilver deposits of the Del Puerto area, Stanislaus County, California: U. S. Geol. Survey Bull. 936-D, pp. 79-110, 1942.

Myers, W. B., and Everhart, D. L., Quicksilver deposits of the Guerneville district, Sonoma County, California: California Jour. Mines and Geology, vol. 44, pp. 253-277, 1948.

Ross, C. P., Quicksilver deposits of the Mount Diablo district, Contra Costa County, California: U. S. Geol. Survey Bull. 922-B, pp. 31-54, 1940.

Ross, C. P., Quicksilver deposits of the Mayacmas and Sulphur Bank districts of California, a preliminary report: U. S. Geol. Survey Bull. 922-L, pp. 327-353, 1940.

Yates, R. A., and Hilpert, L. S., Quicksilver deposits of central San Benito and northwestern Fresno Counties, California: California Div. Mines Rept. 41, pp. 11-35, 1945.

Yates, R. A., and Hilpert, L. S., Quicksilver deposits of eastern Mayacmas district, Lake and Napa Counties, California: California Div. Mines Rept. 42, pp. 231-286, 1946.

cury deposits differ in detail, their broad geological features are generally similar. The relatively few mercury mines in California that are outside of the Coast Ranges province are less similar.

Cinnabar at the Altoona mine in northeastern Trinity County has been deposited in veins along a contact zone between serpentine and an altered acidic intrusive rock.[7]

At the Walibu (Cuddeback) mine, 10 miles northwest of Tehachapi in Kern County, mercury ore occurs in one of several rhyolite dikes that have intruded granitic rocks of the Sierra Nevada batholith. Cinnabar, the only mineral of economic importance, "encrusts fracture walls, fills small breccia veins . . . and is disseminated as minute crystals through the more altered rhyolite."[8]

The Walibu mine is the southernmost of several mercury occurrences along the eastern flank of the Sierra Nevada. Small amounts of quicksilver have been obtained from Recent hot spring deposits in the Coso district of southwestern Inyo County. The mercury deposits in this area are chiefly in siliceous sinter most of which has been deposited on granitic rock. But some deposits have formed in alluvium that has been altered by action of the hot springs.[9]

The mercury deposits in the Diamond Creek area of Del Norte County are reported to occur as fissure fillings in altered diorite and in quartz veins contained in serpentine.[10]

In the Beaver Creek area of Siskiyou County, cinnabar has been deposited as fracture fillings in metamorphic rocks.[11] In deposits near Tustin, Orange County, cinnabar and native mercury are associated with small veins of barite in Tertiary sandstone country rock.[12]

Utilization. Mercury is the only pure metal that is liquid at ordinary temperatures. It has a low vapor pressure. When heated to its boiling point it oxidizes to a red crystalline powder. It is a good solvent for gold, silver, cadmium, tin, bismuth, lead, and zinc. Mercury compounds are poisonous; some are explosive.

Most of the uses of mercury stem from these properties; but many of the uses, from year to year, consume markedly different proportions of the total annual U. S. mercury consumption. In 1947 approximately 50 percent was used in the manufacture of industrial control instruments and electrical apparatus, 18 percent was used in agriculture, 16 percent in catalysts, 10 percent in pharmaceuticals, and the remainder in dental preparations, munitions, blasting caps, antifouling paint, amalgamation, in the manufacture of vermillion paint, the electrolytic preparation of chlorine and caustic soda, and in general laboratory and miscellaneous uses.[13]

The most familiar uses of mercury are as an expanding metal in thermometers and as a weight to balance atmospheric pressure in barometers. Variations of these instruments are used in many types of pressure

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[7] Ransome, A. L., and Kellogg, J. L., op. cit., p. 474.

[8] Bailey, E. H., and Swinney, C. M., Walibu quicksilver mine, Kern County, California: California Jour. Mines and Geology, vol. 43, pp. 9-14, 1947.

[9] Ross, C. P., and Yates, R. G., The Coso quicksilver district, Inyo County, California: U. S. Geol. Survey Bull. 936-Q, pp. 395-416, 1943.

[10] Ransome, A. L., and Kellogg, J. L., op. cit., pp. 375-376.

[11] Ransome, A. L., and Kellogg, J. L., op. cit., pp. 457-459.

[12] Ransome, A. L., and Kellogg, J. L., op. cit., p. 416.

[13] Meyer, H. M., and Mitchell, A. W., Mercury: Minerals Yearbook 1947, p. 772, 1949.

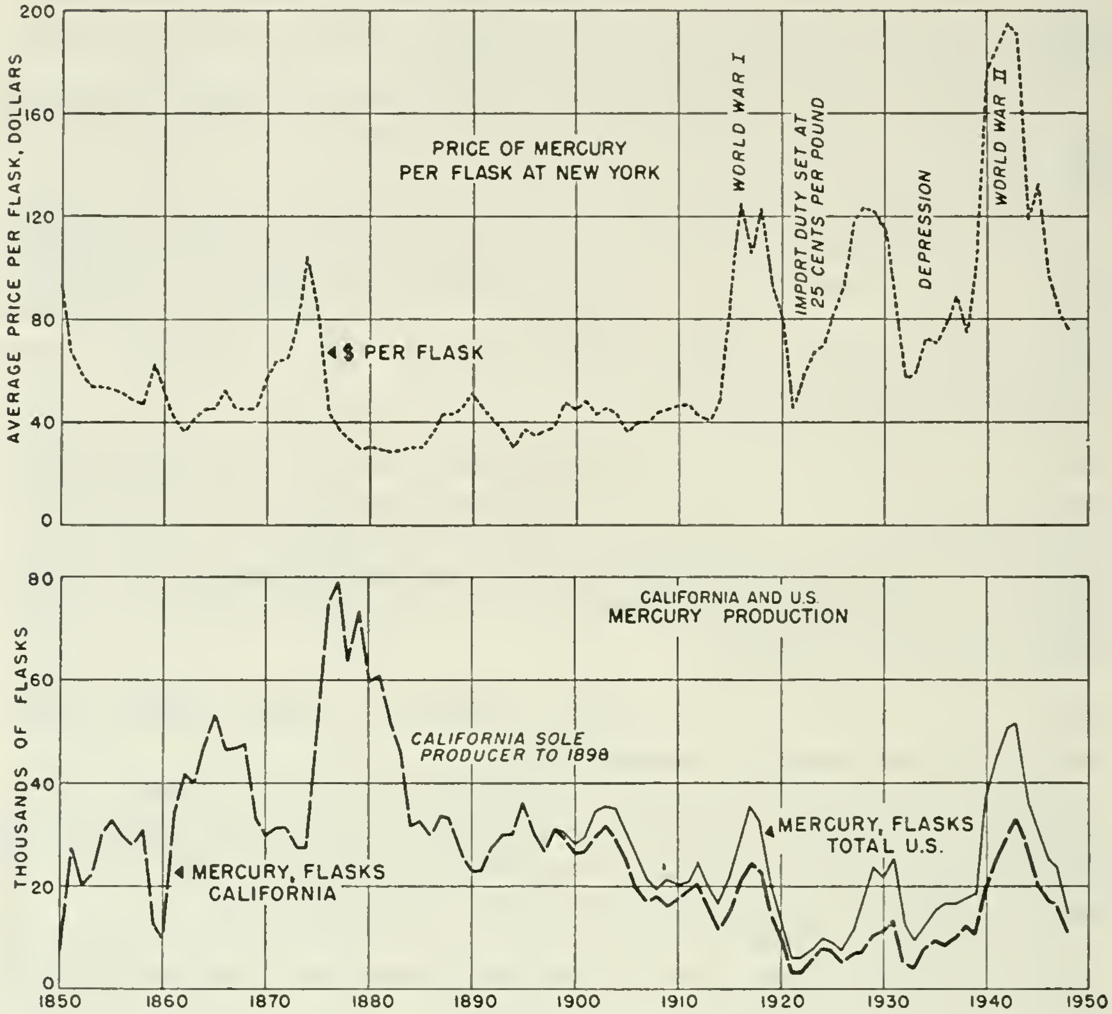

Figure 1. Chart showing production of mercury in California and the United States, and the average price per flask, 1850-1948.

gauges and automatic pressure and temperature control devices. Electrical applications of mercury include use in various types of mercury-vapor lamps; in mercury arc rectifiers and oscillators; and in dry cells, several new types of which were developed during World War II.

Mercury compounds are employed in agriculture as seed disinfectants and antiseptic plant germicides. They are now also extensively applied as mildew and rot preventives for fabrics and leather, a use developed during World War II.

The extraction of gold by amalgamation with mercury was once the principal use but is now much less important. Amalgams of gold, copper, and zinc (solutions of these metals in mercury) are, however, extensively used as dental materials.

In the past large amounts of mercury were consumed in the production of mercury fulminate for use as a detonator in munitions and blasting caps; several other materials are now being substituted for mercury fulminate and its use is diminishing.

Markets. Since the close of World War II mercury producers of the United States have been faced with a lowered price in a buyer's market while cost of operations, equipment, supplies, and labor climbed higher.

Peacetime consumption of mercury in the United States has been increasing and is now but little below that of wartime, largely owing to the success of the mercuric oxide dry cell and increased agricultural use. These developments have been favored by the low post-war price of mercury, but the low price has caused the shutdown of nearly all the California producers.

The pertinent factors influencing the post-war mercury industry are (1) large stocks of mercury here and abroad, (2) world production capacity at record height, (3) the extreme need of dollar credits by foreign countries, (4) the low production cost of Spanish, Italian, and Japanese quicksilver.[14] A cartel, called Mercurio Europeo, once controlled the marketing of both Spanish and Italian quicksilver. This organization now markets only the Spanish output which is obtained principally from the fabulous Almaden Mines. The extent and richness of the ore of Almaden exceeds by far any other mercury deposit in the world. Thus, with the added advantages of lower labor cost, Spanish mercury can be shipped to the United States with $19.00 per flask import tariff and still be profitably sold at a figure below our production cost.

Mining Methods and Treatment. As zones or bodies of mercury ore are irregular and unpredictable in location, size, and grade, they often require much exploration.

Development by underground drifts generally proceeds along a rather indefinite structure which is seldom veinlike but is generally parallel to, or in, a fault zone. Cinnabar stringers commonly cross the zone. These are prospected by raises, as they occasionally lead to ore bodies. The heavy ground which is characteristic of Coast Ranges mines requires heavy timber support, and square-set timbering is usually employed in large stopes. During World War II the shortage of miners induced installation of mechanical loaders, scraper hoists, and ''jumbo'' drilling equipment for drifting in the larger mines.

The extraction of mercury from cinnabar and metacinnabarite is essentially a distillation process. Heating in the presence of air oxidizes the sulfur and frees the contained mercury as vapor, which condenses to the pure metal on cooling. The sulfur as sulfur dioxide passes out of the system as gas. Simple though the process is, many types of furnaces and condensers have been used. ''Burning'' the ore has been done in two ways, one is similar to baking, the other to roasting. In the ''baking'' type, cylindrical or semi-cylindrical iron retorts, placed on a slant in brick fire boxes, are partly filled with ore. Each retort is sealed excepting for a vapor-outlet pipe in which condensation can take place. Retort operation is in cycles of charging, heating, cooling, and withdrawal of burned ore.

Greater capacity was gained with more continuous operation in the various furnaces built to roast ore by direct heat, but it was not until adoption of the rotary kiln principle that efficient, fully continuous roasting was achieved. The Gould rotary kiln installed first at New Idria in 1918, revolves on a slightly inclined axis and the crushed ore moves down toward the heat source. Very nearly complete extraction of the mercury is accomplished, and the vapors are drawn off at the cooler end through cyclone dust collectors by a blower. Mercury condenses from the vapor in banks of connected vertical pipes and is collected in water which

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[14] King, C. R., The economic aspects of mercury production in California: California Jour. Mines and Geology, vol. 44, pp. 327-333, 1948.

seals the "hopper" openings of the lower pipe connections. Besides efficiency and fuel economy, the rotary kiln also eliminated most of the hazard of mercury poisoning which attended the operation of the older types of furnaces.

The Herreschoff multiple hearth furnace, often used to roast other ores, has been tried on mercury ore with some success.

History of Production. In 1824 the first discovery of cinnabar in the United States was made in the hills south and east of San José, Santa Clara County. This later became the site of the New Almaden mine.[15] The red mineral was not recognized as cinnabar and attempts were made to extract silver from it. Twenty years passed before its identity was learned. Mercury was successfully extracted about 1846. A ready market for the metal was provided by the nearly simultaneous beginning of gold mining in the Sierra Nevada.

Mercury was an essential in the placer miner's equipment to collect gold in the pan, rocker, or sluice box, and as the gold rush grew in importance so also did mercury mining. This is seen in the jump from 7,723 flasks produced in 1850 to 27,779 in 1851, and in the increases of annual production to an all-time peak of 79,396 flasks in 1877. Much of the metal came from the very rich ore of the first discovery which had become known as the New Almaden mines. But in the years following 1860 many other deposits were found in several counties; among the first was the New Idria in San Benito County, which was to become second only to New Almaden in total production. The Knoxville, the Aetna, and the Oat Hill mines became notable Napa County producers, as did the Sulphur Bank and Great Western mines in Lake County.

These and many other smaller mines contributed to the record production of the years 1875-82 inclusive, of from 50,000 to nearly 80,000 flasks per year. The price fell rapidly from the $105.18 average of 1874 to $28.23 in 1882 when a 10 percent ad valorem duty was put on imports of mercury. It was a period of overproduction despite the large consumption for gold amalgamation in hydraulic mining and in pan amalgamation at vein gold mines. Much was exported as well.

At times in following years there were changes in the amount of duty on imported mercury but the price did not appreciably improve until World War I. A price of $114 per flask was reached in 1918, but by 1921 the price had dropped to $44.56. In 1922 a more effective duty of $19 per flask plus growing industrial activity gave new impetus to mercury mining. There was a moderate gain in production up to 1931 when 13,478 flasks were shipped. The price reached an average of $118.84 for 1928 but dropped in 1932 to $52.30 and only 4,102 flasks were produced in the following year.

Following World War I the uncertainty of prices hindered development of the mines and reserves of ore were low in most of the mines. The rich deposits of New Almaden had dwindled before 1895, but moderate production continued until 1925. The New Idria mine was the most important producer from 1895 until 1932, when operations were greatly reduced by the depression and the apparent exhaustion of ore.

The readiness with which foreign mercury could be brought in on rising markets no doubt contributed to the extreme fluctuation of price which had plagued the industry. The start of Civil War in Spain and

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[15] Bailey, E. H., The New Almaden quicksilver mines, op. cit.

growing tension in Europe, however, created a shortage of mercury; prices rose, and mining was stimulated. Production climbed from the low point of 4,102 flasks in 1933, to 33,948 flasks in 1943. The price reached $184.58 (average) for 1942. In the six-year period, 1940 to 1945 inclusive, covering the years of World War II, the price ranged from $113.14 to $184.58, averaging nearly $159.00 per flask at San Francisco. New York prices are usually $5 to $6 higher. For the same period average production was 26,285 flasks per year.

Since 1945 both price and production have fallen owing to abundant stocks of mercury in the United States and abroad, and the inability of the European cartel to control Italian production. The present price of approximately $70 (September 1949) per flask at San Francisco is below the cost of production of most domestic properties, and only a few mines continued operation in California into 1949.

MOLYBDENUM

By Richard M. Stewart

California has numerous occurrences of molybdenum minerals, and molybdenum ore has been produced intermittently since 1916. Most of it has been a by-product of the Pine Creek tungsten operation and in recent years the state's molybdenum output has reflected the activity at this tungsten mine. The peak molybdenum production was obtained in the period 1941-43 when over $3\frac{3}{4}$ million pounds were produced in the state. During this period California ranked among the first six molybdenum-producing states. Of all the alloying elements utilized in steel manufacture, molybdenum is the only one in which the United States is self-sufficient. This country's molybdenum resources constitute a larger percentage of known world resources than that of any other metal in common use.

Mineralogy and Geology.[1] Almost all of the world's molybdenum is obtained from the primary mineral molybdenite (MoS_2). Wulfenite ($PbMoO_4$), a minor source of molybdenum, is relatively common in the oxidized zone of some galena- and molybdenite-bearing deposits. Powellite [$Ca(Mo,W)O_4$], an oxidation product of molybdenite, is of little commercial importance.

Molybdenite has a wide range of geologic occurrences, but nearly all are in deposits genetically related to acidic igneous rocks. Commercial quantities of molybdenite have been recovered from fissure veins, disseminated replacement and contact-metamorphic deposits, and pegmatites. In the world's largest molybdenum deposit at Climax, Colorado, molybdenite occurs with quartz and orthoclase in veinlets within altered portions of a granite mass. A mine at Questa, New Mexico, obtains molybdenite from quartz veins in granite. Disseminated copper deposits of the western United States contain minor amounts of molybdenite. The copper deposits at Bingham, Utah, where molybdenite is recovered as a by-product, have become the world's second largest molybdenum source.

Contact-metamorphic deposits, such as those which are worked for tungsten at Pine Creek in California, commonly contain recoverable amounts of molybdenite. Though molybdenite is an accessory mineral

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[1] Hess, F. L., Molybdenum deposits, a short review: U. S. Geol. Survey Bull. 761, 35 pp., 1924.

in some granites, pegmatites, and aplites, it rarely occurs as commercial concentrations in these rocks. Nevertheless, a small portion of the molybdenite mined in California was obtained from aplite dikes.

Localities. Molybdenum mineralization has been found in several counties in California,[2] and production has been reported from Inyo, Mono, Plumas, San Diego, and Shasta. Most of California's production has come from the Pine Creek tungsten mine near Bishop, Inyo County. The mine is worked primarily for tungsten, but relatively large amounts of molybdenum and lesser amounts of copper, gold, and silver are recovered.[3]

The tungsten and molybdenum ore bodies at Pine Creek are near the north end and on the west side of an elongate block of metamorphic rocks surrounded by intrusive granite and quartz diorite. The contact zone consists of tactite, quartz, and quartz-feldspar rocks. Molybdenite and powellite are present in all of the five known ore bodies. In two of these, molybdenite is in well-defined ore shoots which are more closely associated with the quartzose parts of the contact zone than with the tactite. The molybdenite is recovered from all of the ore milled and the average grade has been about 0.40 to 0.45 percent MoS_2.

The molybdenum produced in Mono County in 1917 was obtained from a deposit 4 miles west of Sweetwater, Nevada, close to the California-Nevada line. The molybdenite occurs as stringers in an altered granite. The 1934 Mono County production was obtained from the Sunset claims near Bridgeport, but no other data are available on this deposit.

Molybdenite-bearing aplite dikes have been sources of molybdenum in San Diego and Shasta Counties. Production has been recorded from three deposits of this type. In San Diego County,[4] one is in the vicinity of the Campo feldspar deposit,[5] and another is 6 miles west of Ramona. The Shasta County deposit is 4 miles west of Gibson.[6]

The Plumas County molybdenum production was obtained as a by-product at the Murdock copper mine near Chilcoot.

Utilization.[7] The steel industry consumes about 70 percent of all the molybdenum used in the United States. Molybdenum has no deoxidizing or scavenging properties, and its use is strictly that of an alloying element. It is one of the best and most versatile alloys in the production of high-quality steel. The increased consumption of molybdenum for this metallurgical use has made possible the large-scale development at Climax.

Molybdenum can be substituted for tungsten in high-speed steels, and large amounts are so utilized. Almost all nitriding or case-hardening steels contain molybdenum, which adds to their strength. When molybdenum is added to stainless steels, the resistance to chemical corrosion is increased. Molybdenum is one of the best additives for providing high-temperature strength for such uses as in jet-propulsion engines, and is

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[2] Dolbear, S. H., Economic mineral resources and production of California: California Div. Mines Bull. 130, pp. 182-183, 1945.

[3] Bateman, P. C., Pine Creek and Adamson tungsten mines, Inyo County, California: California Div. Mines Rept. 41, pp. 231-249, 1945.

[4] Tucker, W. B., and Reed, C. H., Mineral resources of San Diego County: California Div. Mines Rept. 35, pp. 30-31, 1939.

[5] See section on Feldspar in this bulletin.

[6] Averill, C. V., Mineral resources of Shasta County: California Div. Mines Rept. 35, pp. 168-169, 1939.

[7] Petar, A. V., Molybdenum: U. S. Bur. Mines Econ. Paper 15, 38 pp., 1932.
Phillips, W. H., Molybdenum, in Mathewson, C. H., and others, Modern uses of non-ferrous metals, pp. 217-228, Am. Inst. Min. Met. Eng., 1935.

one of the few alloying elements which does not adversely affect the weldability of the steel. Molybdenum is also commonly used to improve the strength and toughness of cast iron.

Pure metallic molybdenum, which is a soft, ductile, white metal, finds many applications as finished rod, wire, or sheet. As wire 0.003 to 0.050 inches in diameter, molybdenum is used for filament supports in incandescent lights, and grid elements in radio tubes. It is used extensively in the form of ribbon, 0.006 to 0.010 inches thick, for heating elements in electric-resistance furnaces. Temperatures up to 2000°C. (3630°F.) can be obtained. Molybdenum electrical contact points give excellent results.

Molybdenum is also used in the preparation of inks and fast dyes; with nickel it serves as a catalytic agent in the hydrogenation of oils; lead molybdate is an opacifying agent in the production of glass enamels.

Mining Methods and Treatment. At the Pine Creek tungsten mine, sub-level caving methods employing diamond-drilled blast holes are used the most, but some shrinkage stopes are still active. In contrast to this operation is the large-scale block-caving system employed at Climax, Colorado, where in 1943, at the peak of production, 20,000 tons of ore were mined and milled per day.

The shipping product is a concentrate; the milling and concentration of molybdenum ores is fairly simple, as molybdenite is one of the most easily floated minerals.

For use in the steel industry, this concentrate normally must be converted to either molybdic oxide, calcium molybdate, or ferromolybdenum. The molybdenite concentrate is roasted to technical grade molybdic oxide at temperatures controlled to prevent high volatilization loss. This technical grade oxide is the raw product for conversion to other materials. Upon volatilization in an electric furnace at approximately 1800°F., this oxide will form pure molybdic-oxide powder.

Calcium molybdate can be made either by adding lime on the oven hearth, after sulfur elimination in the concentrate is nearly complete, or by mechanically mixing uncalcined high-quality limestone with the roasted concentrate. Calcium molybdate normally contains 35 to 40 percent Mo.

Ferromolybdenum is usually made by the thermite process. At the Langeloth, Pennsylvania, plant of the Climax Molybdenum Company, a mix is used containing 1300 pounds of molybdenum in oxide, 116 pounds of 93 percent aluminum, 1122 pounds of 50 percent ferrosilicon, 618 pounds of iron ore, 160 pounds of lime, and 50 pounds of fluorspar. The reaction is complete in 15 to 20 minutes, and results in a slag-covered button of ferromolybdenum weighing around 2000 pounds. It is cleaned of slag and crushed to market size.

Molybdenum metal is made by dissolving the oxide in ammonia and precipitating ammonium molybdate. This is reduced to molybdenum dioxide which is heated in a current of hydrogen at 900° to 1000°C. to produce a grayish-black powdered metal. This metal is pressed into 12-inch bars, a quarter to half an inch thick, and heated between contacts in hydrogen to just below the melting point. The result is a 10 percent porous bar which can be hot-worked to fine wire, sheet, or rod.

Markets.[8] In 1948 California was the fourth largest molybdenum-producing state. Of the 26,706,000 pounds of contained molybdenum in concentrates produced in the United States in 1948, slightly more than half was from mines operated principally for molybdenum; the remainder was by-product molybdenum from copper or tungsten operations.

Exports of molybdenum concentrates totaled 4,132,341 pounds of contained molybdenum, going chiefly to France and the United Kingdom. A large part of California's production is exported. No molybdenum concentrates were imported during 1948.

Conversion of concentrates to the various market products is done by the two principal molybdenum companies at Langeloth and Washington, Pennsylvania.

Prices for the principal molybdenum products marketed are given below for 1948.[9]

Molybdenum metal 99 percent $2.60 to $3.00 per pound

Ferromolybdenum (55 to 65 percent Mo)	95 cents	Per pound of contained molybdenum
Molybdic oxide	80 cents	
Calcium molybdate	80 cents	

Molybdenum ore was valued at 45 cents per pound of contained MoS_2 on a basis of 90 percent concentrate, f.o.b. mines, until December 1, 1948, when the price was raised to 54 cents.

History of Production. The first recorded production of molybdenum in California was from Plumas County in 1915. In 1916 small outputs were recorded from Plumas and Inyo Counties. During 1917 production from Inyo County was continued and Mono, San Diego, and Shasta Counties were also listed as sources. In 1918 Shasta County had the only production.

After the end of World War I, the demand for molybdenum was slight and no ore was mined in California until 1933, when some was mined in both Inyo and Mono Counties. This ore was shipped from Inyo County that year and from Mono County in 1934.

Production was resumed again from Inyo County in 1939 and was continued through 1944. Production in 1943 was the largest of any year. In 1945 the Pine Creek tungsten mill was shut down and there was no molybdenum production. Operations were resumed in 1946 and have continued to date.

PLATINUM AND ALLIED METALS

By Clarence A. Logan

For many years an average annual production of a few hundred ounces of platinum and other metals of the platinum group has been obtained as a by-product of placer gold operations in California. Since 1850 more than 25,000 ounces of these metals have been produced in the state. About three-quarters of this output has been obtained since 1900 when recovery of the platinum metals was encouraged by an increase in prices.

California has been the foremost state in the production of platinum metals, but more than three-quarters of the domestic output is now being contributed by Alaska. The domestic sources of these metals are limited and have in the past supplied only a small part of the nation's annual

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[8] Molybdenum in 1948: U. S. Bur. Mines, Mineral Industry Surveys, Mineral Market Rept., MMS 1711, 1949.

[9] Eng. and Min. Jour., Metal and Mineral Markets, vol. 20, New York, McGraw-Hill Publishing Co., Jan. 6-Dec. 30, 1948.

requirements either in peace or war. During World War II the platinum metals had many strategic uses, and their consumption in non-essential industries was curtailed.

Mineralogy and Geologic Occurrence. Platinum is one of a group of six related precious metals: ruthenium, rhodium, palladium, osmium, iridium, and platinum. All have very high specific gravities and are insoluble in most acids. So-called crude platinum is generally an alloy of two or more metals of this group. Some specimens also contain iron and other metals.

Native platinum and palladium commonly occur as smooth thin flakes; platiniridium (platinum, iridium) commonly occurs as rounded or angular grains; and iridosmine (iridium, osmium) and siserskite (osmium, iridium) are found as cleavage flakes or irregular flattened grains, sometimes as relatively large nuggets. If the proportion of either iridium or osmium is high in a mineral, the alloy will have a hardness of six to seven. Iridosmine pertains to the mineral containing more iridium than osmium, and siserskite to the mineral containing more osmium than iridium. Both minerals usually contain one or more of the other members of the family.

The platinum minerals are widely distributed throughout the world but only in a few areas are they recovered commercially. Almost all of the primary occurrences have been deposited by magmatic processes in basic or ultrabasic rocks. The erosion of such magmatic concentrations has provided the placer deposits which in the past have yielded most of the world's platinum metals. Of these, the placer deposits of the Ural Mountains in Russia have been by far the most productive. Since 1934 the massive nickel-copper sulfide bodies at Sudbury, Ontario, have been a major source of platinum metals. The Sudbury ores are associated with a large norite-micropegmatite intrusion and contain disseminated platinum as a minor constituent.

Localities. The placer deposits from which most of the platinum metal production in California has been obtained are largely confined to two areas: (1) a belt in northwestern California embracing parts of Del Norte, Siskiyou, Humboldt, Trinity and Shasta Counties; and (2) a 180-mile belt paralleling the Sierran foothills and extending from Merced County north-northwestward to Butte County.[1] In nearly all of the placer deposits of California the proportion of platinum metals to gold is small. This proportion, as indicated by dredge recovery, has ranged from 1 ounce to one-third of an ounce of platinum metal for every 50 ounces of gold.

In California the production of platinum metal has come largely from bucket dredges. The largest dredging fields in the Sierran foothill belt have been along the American River in the Folsom district, Sacramento County; the Feather River near Oroville, Butte County; and the Yuba River near Hammonton, Yuba County. Merced and Stanislaus Counties have also been producers. The placers of the American River, which drains large areas of serpentine and related basic igneous rocks, have yielded the highest proportion of platinum to gold.

Platinum-group minerals recovered on the American River contain from 37 to 46 percent platinum and 16 to 35 percent iridium. The Yuba

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[1] Logan, C. A., Platinum and allied metals in California: California Min. Bur. Bull. 85, pp. 14-15, 1918.

River platinum-group minerals contain from 60 to 69 percent platinum and from 15 to 19 percent osmiridium.

The largest nuggets of platinum minerals found in California have been obtained from hydraulic mines near Junction City, Trinity County. Some of these nuggets weigh an ounce or more. The platinum metals obtained in dredges on the Trinity River generally contain more iridium and osmium than platinum. In the material from some of the other northern streams the iridium and osmium are greatly in excess of the platinum.

The primary source of most of the platinum metals in the placer deposits of California is believed to have been in serpentine and related basic and ultrabasic rocks. No deposits of platinum ore have been found in the state, but a few assays indicating platinum have been reported. Blister copper from the Iron Mountain mine, Shasta County, has carried some platinum.

Utilization. In the past the jewelry trade has consumed about 50 percent of the platinum metals used in the United States. Since 1934 the total uses for all of the platinum metals has increased nearly fourfold. The most significant trends have been the very large increase in the use of both platinum and palladium in electrical apparatus, such as contact points in magnetos, spark coils, and spark plugs. The degree to which palladium has displaced platinum for such uses is noteworthy.

In the chemical industry, one of the leading uses for platinum metals is as a catalyst in making nitric acid from a mixture of air and ammonia by passing the mixture through red-hot gauze made from an alloy of platinum and rhodium. Other chemicals are also made with the help of this alloy as a catalyst. Palladium and platinum serve as catalysts in processes of hydrogenation and dehydrogenation. Palladium has the property of absorbing several hundred times its volume of hydrogen and retaining it until heated in a vacuum.

Because of its great resistance to corrosion, oxidization, and the action of acids, no substitute has been found for platinum in making laboratory equipment. In many of its applications platinum is hardened by the addition of up to 10 percent of iridium. Palladium or platinum alloyed with gold produce dental metal with superior tarnish resistance, strength, and response to age-hardening treatment. Such uses also account for a large proportion of the platinum-group metal consumption in the United States.

Markets. Though relatively small amounts of crude platinum-group metals are produced in California, the state does consume large quantities of the refined metals, principally in jewelry, chemical apparatus, and dental metallurgy. Some crude platinum is bought for use in California.

Mining Methods and Treatment. Except for the placer mining operations in the Goodnews Bay district of Alaska, crude placer platinum in North and South America is generally recovered as a by-product of gold-placer mining. The mining and recovery methods, therefore, range from hand panning to large bucket dredges. As platinum metals do not amalgamate with mercury without special treatment, they must be saved by panning, or by the use of jigs or other means of mechanical concentration after the gold has been removed from the black-sand concentrate.

The platinum metals which occur in sulfide ores, such as those of the Sudbury mines in Canada, are recovered from the anode mud of the electrolytic cells used in copper refining. At the Witwatersrand gold deposits in South Africa osmiridium is saved by concentration on corduroy. The separation of the different members of the platinum group, a long and complicated chemical process, has been described by Duparc.[2]

History of Production. Substantial amounts of crude platinum were thrown away in the early days of gold-placer mining in California, because if salable at all, platinum brought only a few dollars an ounce. The low price of $4 to $6 an ounce persisted until 1902, when it began to rise, reaching $48 an ounce in 1913. During, and for a few years after, World War I when the supply from Russia was interrupted, good prices were paid. A maximum price of $154.23 per fine ounce was realized in January 1920. Prices paid have fluctuated between wide limits in recent years but have had little effect on production, as all platinum metals produced locally have been by-products.

The period 1936-41, which was one of marked activity in gold dredging, was naturally a time of increased production of platinum metals. In 1940 a maximum of 1358 fine ounces was produced in California. Since 1943, with the curtailment of placer mining caused by the war, platinum metal output has dropped to a 40-year low. There was also less incentive to save platinum metals because of government controls during the war; platinum was held at $35 a fine ounce, palladium at $24 a fine ounce, and iridium at $90 to $100 a fine ounce. On May 6, 1946, the controls on platinum were lifted and the price increased at once to $56 a fine ounce, rising to $93 at the end of 1948. At present (July 1949) platinum is quoted at $69, iridium at $100, rhodium at $125 and osmium at $100 per fine ounce troy. The price of palladium, produced principally in Canada, has been held at $24 a fine ounce, largely to increase its use.

SILVER *

By Richard M. Stewart

Silver has been produced in quantity in California since the gold-rush days. Statistics covering the state's annual silver output were not gathered previous to 1880, but since then over 100 million ounces have been produced. This represents about 2.8 percent of the national output for the corresponding period. In 1948 the state's silver output dropped to less than half of the 1947 production and was about 1.8 percent of the United States total. Most of the state's silver has been produced from base-metal mines. This has been especially true in recent years, but in two districts silver has been the principal valuable metal.

Mineralogy, Geologic Occurrences, and Localities.[1] The most important silver minerals of California are cerargyrite (AgCl), also known as horn silver; and miargyrite ($AgSbS_2$). Tetrahedrite [$(Cu,Fe)_{12}Sb_4S_{13}$] if silver bearing, is called freibergite. Freibergite is common in many mines in California and was very important in several deposits. Most of

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[2] Duparc, Louis, et Tikonowitch, M., Le platine et les gites platinifèrs d'Oural et du Monde, "Soner," Geneva, 1920.

* Merrill, C. W., and Meyer, H. M., Gold and silver: Minerals Yearbook 1946, pp. 557-587, 1948.

Mine production of silver in the United States in 1948: U. S. Bur. Mines, Mineral Industry Surveys, Mineral Market Rept. 1690, 5 pp., 1949.

[1] Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, pp. 251-304, 1917.

Murdoch, Joseph, and Webb, R. W., Minerals of California: California Div. Mines Bull. 136, 1948.

the silver now produced in California is obtained from argentiferous galena and silver-bearing oxidation products of lead-zinc ores.

Native silver, principally as a secondary mineral, is widespread, but ordinarily is not as abundant as other silver-bearing minerals. Native silver is seldom pure but contains admixtures of other elements, particularly gold and copper. Electrum, an alloy of gold and silver, carries from 18 to 36 percent silver. Practically all lode gold carries substantial amounts of silver and an appreciable amount of California's silver production has been obtained from lode-gold mines. The silver content of most of the lode gold produced in the state, however, has been relatively low.

Silver minerals that are important in other areas are argentite (Ag_2S); proustite (Ag_3AsS_3), also known as light ruby silver; and pyrargyrite ($Ag_3Sb\ S_3$), also known as dark ruby silver.

In California, as well as in the rest of the United States, most of the current silver production is obtained from base-metal ores. The lead-zinc operations in the Darwin and Tecopa districts of Inyo County have been the principal silver producers in Califorina in recent years. These districts are described in the section on lead in this bulletin. These and other similar deposits have given Inyo County a total silver production which ranks third among the counties of the state. San Bernardino and Shasta Counties have respectively the first and second largest total silver outputs. Most of the silver produced in Shasta County has been as a by-product of copper-zinc mines. These are described in the sections on copper and zinc in this bulletin. Other counties that have produced silver valued in excess of one million dollars are Calaveras, Kern, Mono, Nevada, and Plumas.[2]

San Bernardino County, the state's principal silver source, has a total silver output valued at nearly 30 million dollars. Although some of this silver has been obtained from base-metal or gold mines, most of it was obtained from mines in which it was the principal ore metal. The mines of the Calico district and the California Rand silver mine of the Randsburg district have yielded most of this production.

In the Calico district,[3] which was active from 1883 to 1895, the ore was principally cerargyrite with some embolite [Ag(Br,Cl)]. These were in a gangue consisting predominantly of barite and jaspery silica. Base-metal minerals and gold were minor. The areal geology of the district is characterized by Tertiary andesite flows that probably rest on a unexposed granitic complex. Overlying these flows is a series containing sedimentary lake beds, tuffs, and volcanic flows. Faulting is complex and includes some thrusting. The ore occurred in veins in, or associated with, prominent fault fissures, and in irregular, pockety, deposits. The richest ore was obtained close to the surface, but some of the veins continued to be rich with depth. The deposits of this district have been classified as epithermal.

The California Rand silver mine (Kelly) was discovered in 1919. The veins in this mine are deposited along two pre-mineral fault sys-

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[2] Dolbear, S. H., Economic mineral resources and production of California: California Div. Mines Bull. 130, 1945.

[3] Erwin, H. D., and Gardner, D. L., Notes on the geology of a portion of the Calico Mountains, San Bernardino County, California: California Div. Mines Rept. 36, pp. 293-304, 1940.

Storms, W. H., The Calico mining district: California Min. Bur. Rept. 11, pp. 337-345, 1893.

tems, one striking roughly north and the other striking northeast.[4] All of the commercial ore bodies are in the Rand schist, considered to be of Archean age. Miargyrite is the principal silver mineral with freibergite, pyrargyrite, and proustite following in order of importance. The freibergite was at first considered to be stylotypite.[5] Gold was important but less so than silver. Up to 1924, the average ratio for the shipping-grade ore was 441 ounces of silver to 1 of gold; for the milling-grade ore, 264 of silver to 1 of gold. The gold is thought to have been deposited by different solutions than those depositing the silver. The gangue consisted largely of fine-grained, bluish-gray to dark-gray quartz and some calcite, chalcedony, and opal. Inclusions of angular schist fragments were abundant as were open drusy cavities. The deposits have been classified as epithermal and were probably formed in the early upper Miocene.

Utilization.[6] Silver has been used by man for thousands of years. The malleability and ductility of the native metal allowed it to be shaped even with the crudest of tools. Owing to its relative scarcity and its stability under normal conditions, its principal use from earliest times has been as a measure of wealth and as a medium of exchange.

Utilization of silver in coinage is not as great today as it once was. During 1948 approximately 25,000,000 ounces were consumed for domestic coinage. This was for coinage other than silver dollars, which were not minted.[7] The intrinsic value of silver coins depends upon the weight and fineness of the silver, and the monetary value may be greater or less. Binary silver-copper alloys are the ones principally used in coinage, the copper providing greater resistance to wear. The fineness of coinage alloys varies from 500 to 900. The standard United States dollar is 900 fine, weighs 26.7296 grams, and contains 371.5 grains of fine silver.

Domestic consumption of silver in the arts and industry during 1948 is estimated at 110,000,000 ounces. Nearly two-thirds of this was used in silverware—both sterling and plate. The standard alloy for tableware is sterling silver, which is a silver-copper alloy with a silver fineness of 925.

Silver is an excellent conductor of heat and electricity and was used extensively during World War II in place of copper. Large amounts of silver were loaned to industry from the monetary stocks of the treasury for uses such as in bus bars. Silver is also used in electrical contacts, commonly in silver-molybdenum or silver-tungsten mixtures prepared by powder metallurgy processes.

Silver solders and brazing alloys are widely used for making joints which have great strength and are highly resistant to corrosion. Copper, zinc, tin, and cadmium are the normal alloying elements in this application.

The use of silver nitrate by the photographic industry consumes large amounts of silver each year. The medical and dental professions employ silver in many ways. The resistance of silver to corrosion is a property utilized in making certain laboratory equipment. Silvering glass for mirrors is a common use. The jewelry trade uses much silver, either as sterling or as gold-silver alloys.

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[4] Hulin, C. D., Geology and ore deposits of the Randsburg quadrangle of California: California Min. Bur. Bull. 95, 152 pp., 1925.

[5] Murdoch, Joseph, and Webb, R. W., op. cit., p. 288.

[6] Leach, R. H., Silver, in Mathewson, C. H., and others, Modern uses of nonferrous metals, pp. 326-342, Am. Inst. Min. Met. Eng., 1935.

[7] Handy and Harmon, 33d Ann. Rev. of the Silver Market, 1948.

Silver Refining. As silver always occurs with varying amounts of gold, even in the base-metal ores, the metallurgical product which has to be refined is a gold-silver bullion, or doré. Gold ores, gold-silver ores, and all of the base-metal ores from which the precious metals are recovered are processed differently, but all yield a gold-silver bullion.

The separation of the silver from the gold in this bullion, or doré, is effected by either dry, wet, or electrolytic methods.[8]

The dry method consists of converting the silver to a chloride or sulfide while the bullion is molten. In the Miller process chlorine gas is passed through the molten bullion, making silver chloride which is further refined to pure silver.

In the wet method the silver is dissolved by either nitric or sulfuric acid and subsequently recovered from the salt formed. Because of its cheapness sulfuric acid is generally used. The ratio of the silver to gold in the bullion must be approximately 3 to 1.

Several electrolytic methods are used and have to a large extent replaced or supplemented the acid-parting systems. The Moebius and Balbach processes are used for silver-predominant bullion and the Wohlwill process for gold-predominant bullion.

Theoretical fine silver would be 1000 fine, but the standard in this country is 999. Reputable refineries usually maintain a product of 999.2 to insure the acceptance of their silver.[9] Modern refining methods can produce such fine silver that copper is sometimes added to bring the fineness down to the accepted standard. The fineness of the silver is stamped upon each bar.

Markets. California's 1948 silver production was 724,771 fine ounces. Of this nearly 80 percent was derived from lead and lead-zinc ores, and nearly 60 percent from the operations at Darwin and Tecopa.[10] California was seventh among the silver-producing states in 1948, sixth in 1947. Idaho, which produces most of its silver from silver ores, was the leading producer in 1948 with 11,550,000 fine ounces. The total United States production in 1948 was 37,790,080 fine ounces.

Silver imports totaled an estimated 96,000,000 ounces in 1948. Of this about 11,000,000 ounces were in coin.[11] The remainder was made up of approximately 40 percent in ore or base bullion and 60 percent in refined bullion.[12] Over 40 percent of the imports originated in Mexico, which is the principal silver-producing country in the world.

Governmental purchase of newly mined domestic silver was started by presidential proclamation in 1933 at a price of 64.4 cents per ounce, and continued at various prices until 1939, when the price was set at 71.11 cents. Later, the act of July 31, 1946, set it at 90.5 cents. This last act still governs the purchase of all newly mined domestic silver. During the war years silver was channeled into industry; except for that period, however, the Treasury has acquired all new silver produced in the United States.

In 1948 the New York market price for foreign and secondary silver reached a high of 77½ cents per ounce in October and a low of 70 cents per ounce in November.[13]

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[8] Wagor, E. J., Refining of gold and silver bullion, in Lidell, D. M., and others, Handbook of nonferrous metallurgy, vol. 2, pp. 275-288, New York, McGraw-Hill Book Co., 1945.

[9] Leach, R. H., op. cit., p. 329.

[10] U. S. Bur. Mines Mineral Market Rept. 1690, op. cit.

[11] Handy and Harmon, op. cit.

[12] Oscarson, R. O., Silver: Mining World, vol. 11, no. 5, pp. 37-38, April 1949.

[13] Handy and Harmon, op. cit.

Smelters do not make payment on all of the silver in the ores and concentrates but vary the payment rate depending on the type of ore and the amount of silver in the concentrate. Payment is normally based on the treasury price. Typical silver payments for base-metal ores are as follows: [14]

1. In copper ores and concentrates payment is made for 95 percent of silver if it is in excess of 1 ounce per ton.
2. In lead ores and concentrates payment is made for 95 percent of silver if it is in excess of half an ounce per ton.
3. In zinc concentrates payment is made for 80 percent of the recovered silver if it is in excess of 1 ounce per ton.

History of Production. The production of silver in California was not separately recorded until 1880. The earliest mention of silver mining refers to the Alisal Ranch, Monterey County. Prior to 1825 an adit and winze were supposedly driven here by three Chileans under the direction of Spanish padres. The ore was galena, thought to be argentiferous.[15]

Since 1849 by-product silver produced from the gold mines has been quite important. With mining interest concentrated on gold, little attention was paid to silver. However, in 1856 silver ore in the form of silver-bearing tetrahedrite with galena, was discovered in the South Fork mining district of Shasta County.[16] The Chicago mine, not located until 1866, was the principal producer and is credited with production of about $1,000,000. The ore, at first, was actually shipped to Swansea, Wales, for reduction.

The silver boom of the Comstock Lode in Nevada, in 1859 and 1860, finally led to the prospecting for silver in Alpine, Mono, and Inyo Counties, starting in the summer of 1861.[17] The earliest silver mining in Alpine County was not very successful, largely because the sulfide ores were not amenable to the ordinary free-milling processes. Later, Frue vanner concentrators were brought to the Colorado No. 2, the largest producer, and the concentrates were successfully chlorinated, with high recovery of gold and silver.[18]

Silver-bearing ore was discovered on Blind Spring Hill, Mono County, in 1862.[19] The rather rare mineral, stromeyerite, a copper-silver sulfide, was the principal silver mineral. The district, quite active until 1890, is credited with a production of over $4,000,000.

Farther south, in Inyo County, the Cerro Gordo district was discovered between 1862 and 1866; the Darwin district was discovered in the early seventies.

The Calico district, San Bernardino County, was mainly active from 1883-95 but was worked after that date. The district is reported to have produced over $20,000,000 in silver and gold.[20] An early use of the term

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[14] Bramel, H. R., The marketing and metallurgy of complex ores in California: California Div. Mines Bull. 144, pp. 165-167, 1948.

[15] Laizure, C. McK, Monterey County: California Min. Bur. Rept. 21, pp. 23 and 56, 1925.

[16] Tucker, W. B., Silver lodes of the South Fork mining district, Shasta County: California Min. Bur. Rept. 18, pp. 313-321, 1923.

[17] Hanks, H. G., Silver in California: California Min. Bur. Rept. 4, pp. 361-368, 1884.

[18] Logan, C. A., Alpine County: California Min. Bur. Rept. 18, pp. 355-366, 1922.

[19] Ransome, A. L., General geology and ores of the Blind Spring Hill mining district, Mono County, California: California Div. Mines Rept. 36, pp. 159-197, 1940.

Sampson, R. J., and Tucker, W. B., Mineral resources of Mono County: California Div. Mines Rept. 36, pp. 117-156, 1940.

[20] Erwin, H. D., and Gardner, D. L., op. cit.

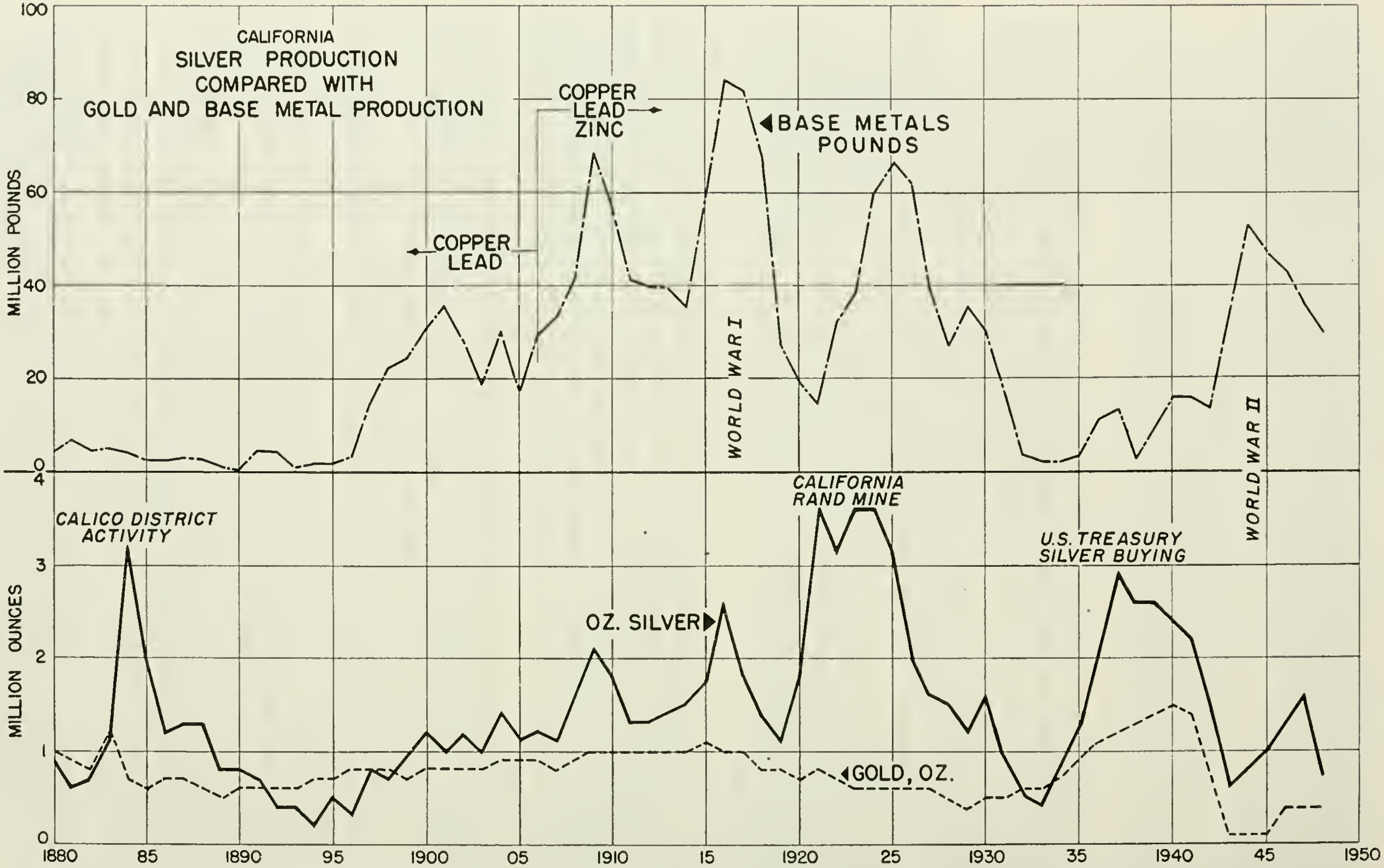

FIGURE 1. Chart showing production of silver in California, compared with production of gold and the base metals, 1880-1948.

"chlorider" was noted here as applying to those who followed and mined only the profitable "chloride" ores and did no development work.[21]

In 1919 the California Rand silver mine was discovered. Several of its subsequent yearly productions were the largest of any silver mine then operating in the United States. It was operated by various companies until it was shut down in 1942. The mine was reopened in 1946. It has contributed more than half of the recorded silver production from San Bernardino County.

The Pittman Act was of importance to silver producers during the period April 1918 to June 1923. Under this act 350,000,000 silver dollars were made available for melting. The silver thus obtained was used by the United States and the Allied Nations to settle trade balances in India, China, and other large silver-using countries.[22] New domestic silver was purchased by the Mint at a guaranteed minimum price of approximately $1.00 per ounce. In June of 1923 the Treasury Department ruled that enough fine silver had been purchased under the Act. Altogether 208,622,056.8 fine ounces were obtained for export by melting of the dollars, but only 200,585,035 fine ounces of new domestic silver were purchased by the Mint.[23]

TIN

By L. A. Norman, Jr.

The important place of tin in the American economy has been well demonstrated in times of peace and war. No adequate substitute has been found for its major use as a protective coating for other metals. In spite of the great demand and high price, the few scattered tin deposits of the continental United States and Alaska have contributed less than 0.02 percent of the world's production.[1] California is among the few states with a recorded production of the metal.

Geologic Occurrence and Localities. Cassiterite (SnO_2) is the principal tin-bearing mineral, but in a few localities stannite ($Cu_2S \cdot FeS \cdot SnS_2$) is of commercial importance. Tin mineralization is widely distributed throughout the world, but in only a few areas are the deposits large enough to be profitably mined. All of the known primary tin deposits are genetically related to silicic igneous rocks, such as granites, granite pegmatites, or quartz veins. Most tin veins have formed under conditions of high temperature and pressure deep beneath the earth's surface. Vein deposits of this type in Bolivia were the principal sources of tin consumed in the United States during World War II. Although wood tin, a nodular variety of cassiterite, occurs in rhyolite flows, prospecting for primary tin deposits is generally confined to areas in which large granitic bodies are exposed.

As cassiterite is extremely resistant to alteration it is liberated by weathering and disintegration of the enclosing rocks; because of its high specific gravity, it is easily concentrated in placer deposits. Placer deposits in southeastern Asia, of which those in British Malaya have been the most

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[21] Storms, W. H., op. cit.

[22] Dunlop, J. P., Gold and silver: Mineral Resources U. S., 1918, pt. 1, p. 740, 1921.

[23] Dunlop, J. P., Gold and silver: Mineral Resources U. S., 1922, pt. 1, pp. 599-600, 1925.

[1] Umhau, John B. Summarized data of tin production: U. S. Bur. Mines Econ. Paper 13, p. 13, 1932.

productive, are the world's principal tin sources. Concentrations of cassiterite occur in eluvial deposits on the slopes immediately below the vein outcrops.

Cassiterite, the only tin-bearing mineral known to occur in California, has been reported at numerous localities most of which are in the southern part of the state.[2]

The tin occurrences in California that have been worked or have attracted attention as possible commercial sources are primary deposits. In the Temescal district, Riverside County, cassiterite is contained in high-temperature tourmaline-quartz veins in a granodiorite country rock. In the Gorman district, Kern County, and the Cima district, San Bernardino County, cassiterite is disseminated in tactite replacement bodies. The tactite is in limestone and is near, or in contact with, granitic masses. The granitic rocks in all three districts are units of the late Jurassic (?) batholithic masses of the Sierra Nevada and southern California.

Three mines in the state have recorded productions of tin. These are the Temescal mine in Riverside County, the Hogan-Mallery (Meeke-Hogan) mine in Kern County, and the Evening Star (Maynard) mine in San Bernardino County.

The Temescal (Caljalco) mine and several neighboring properties which together comprise the Temescal tin district are confined to an area of less than 15 square miles about 5 miles south of Arlington. Here a mass of Woodson Mountain granodiorite contains a system of tourmaline-quartz veins in only a few of which significant amounts of cassiterite have been found. Most are less than a few inches thick, though some, including the vein that has been most worked, have maximum thicknesses of several tens of feet. The larger veins are generally irregular. All of the veins strike about northeast and dip 55°-75° NW. They apparently represent high-temperature replacement of the granodiorite along fissures.

The tin in the veins occurs as disseminations and as bunches and stringers. The ore that was milled is reported to have averaged about 5 percent SnO_2, a grade too low for an economical operation.

The deposits and the regional geology have been described respectively by Fairbanks [3] and Larsen.[4] Sampson [5] has outlined the history of the district and described the mining operations.

The Hogan-Mallery (Meeke-Hogan) mine and several neighboring tin-bearing properties are in the Gorman district of southern Kern County. These deposits are in tactite which has replaced limestone near the border of an intrusive granite body. The cassiterite occurs as scattered grains within the tactite, which is composed principally of limonite, magnetite, and various contact-metamorphic minerals.[6]

The Evening Star mine and other nearby tin-bearing properties are about 8 miles north of Cima in northeastern San Bernardino County. The mine has explored a hematitic pipe which has formed in limestone at

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[2] Bedford, R. H., and Johnson, F. T., Survey of tin in California: U. S. Bur. Mines Rept. Inv. 3876, 14 p., Apr. 1946.

[3] Fairbanks, H. W., The tin deposits of Temescal, southern California: Am. Jour. Sci., 4th ser., vol. 4, pp. 39-42, 1897.

[4] Larsen, E. S., Jr., Batholith of southern California: Geol. Soc. American Mem. 29, pp. 132-133, 1948.

[5] Sampson, R. J., Mineral resources of a portion of the Perris block, Riverside County, California: California Div. Mines Rept. 31, pp. 515-518, 1935.

[6] Wiese, J. H., and Page, L. R., Tin deposits of the Gorman district, Kern County, California: California Div. Mines Rept. 42, pp. 31-52, 1946.

the intersection of two fractures. Cassiterite is disseminated in the pipe, which also is reported to contain scheelite.[7]

Properties other than those in the districts mentioned above, at which tin has been noted in quantities greater than 1 pound per ton of rock sample, include the following: The Lucky Three, Jeanette Grant, Black Jack, Rocky Point, and Big Blue properties in the Isabella district, Kern County; the Greenback Copper and Iran Mountain properties in the Woody district, Kern County; the American Flat and Monarch mines in the Elsinore district, Riverside County; and the Atolia tungsten mines, San Bernardino County.[8]

Utilization and Markets. The usefulness of tin is based upon its easy fusibility, malleability, resistance to corrosion, readiness to alloy with other metals, and its attractive silver color. Because of these properties and the comparatively simple recovery by smelting, it was one of the first metals to be used by man, particularly as a constituent of bronze. Today most of the tin consumed in the United States is used in plating material, solder, bronze, bearing metal, and foil. Smaller amounts are used in type metal, pipe and tubing, chemicals, and for miscellaneous purposes.[9]

The price of tin has fluctuated over a wide range in the last 50 years. Average annual figures range from 13.67 cents per pound in 1897 to 99.25 cents in 1948. During 1948, the price of "Straits" tin, New York, rose from 94 cents per pound in May to 103.0 cents in June, where it remained throughout the year.

Preparation. Tin ore is mined by conventional methods used in placer and lode production of other metals. Malay placer concentrates average about 70 percent tin; the Bolivian lode concentrates average 62 percent. Reduction of the oxide, cassiterite, is accomplished by smelting, using carbon as the reducing agent. Sulfide ores with a high sulfur content are roasted prior to smelting. The crude metal recovered by smelting is refined by electrolysis or by heat treatment. The world smelting centers are situated in British Malaya, United Kingdom, Netherlands, Netherland East Indies, and China. A federal government-financed smelter was placed in operation in 1942 at Texas City, Texas.

History of Production. Tin ore was discovered in the Temescal district, Riverside County, prior to the Civil War, but the first production of record was in 1891. Ore was mined during 1891 and 1892 and later in 1928-29. Approximately 113 long tons of tin were produced from the district.[10]

In 1916 a property in Trabuco Canyon, Orange County, was partly explored in search of commercial quantities of tin, and a mill was erected, but there is no record of production.[11] In 1944 the Hogan Mallery (Mecke-Hogan) mine of the Gorman district, Kern County, produced 5 tons of ore equivalent to 1.93 tons of tin. This was shipped to Metal Reserves Company.[12] Small shipments of ore and concentrates have also been made from the Evening Star mine of the Cima district.

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[7] Bedford, R. H., and Johnson, F. T., op. cit., p. 10.
Tucker, W. B., and Sampson, R. J., Mineral resources of San Bernardino County: California Div. Mines Rept. 39, pp. 498-499, 1943.

[8] Bedford, R. H., and Johnson, F. T., op. cit., pp. 5-11.

[9] Vogelsang, Erwin, 80th annual survey, tin: Eng. and Min. Jour., vol. 150, no. 2, pp. 81-83, 1949.

[10] Segerstrom, R. J., Tin in California: California Div. Mines Rept. 37, p. 543, 1941.

[11] Segerstrom, R. J., op. cit., p. 534.

[12] Wiese, J. H., and Page, L. R., op. cit., p. 33.

San Bernardino County.[13] No tin production has been reported in California since 1944.

TITANIUM

By Gordon B. Oakeshott

Interest in titanium has developed rapidly in the last two years. This has been occasioned by the growing use of titanium dioxide in the paint and ceramic industries, and by the development of a less expensive method of producing metallic titanium. Production in California has been small, but large reserves of ilmenite, the principal source of titanium, are in Los Angeles County.

Geologic Occurrence. All of the world's large titanium deposits are closely associated with such basic rocks as anorthosite, gabbro, and pyroxenite, and are related to them in origin. Ilmenite and titanomagnetite (intergrowth of ilmenite and magnetite) are heavy resistant minerals; they are commonly concentrated in beach sands, stream sands, and sand bars. Prospecting for titaniferous deposits should be confined, therefore, to large bodies of anorthosite and related gabbro and pyroxenite, and to large concentrations of black sands derived from such rocks.

Anorthosite, a coarsely crystalline rock consisting of more than 90 percent plagioclase feldspar, is easily recognized. Most of the large anorthosite bodies in the United States have been mapped; the only large mass known in California is in the western San Gabriel Mountains where its outcrops cover an area of nearly 100 square miles.

Titaniferous deposits in the western San Gabriel Mountains[1] contain titanomagnetite, associated with augite and apatite. The augite has been partly replaced by chlorite and actinolite. The proportions of all these minerals in anorthosite are highly variable. The titanium-bearing rocks are in andesine anorthosite and in gabbro and pyroxenite which grade into the anorthosite. The titanomagnetite-bearing rocks occur as (1) poorly defined, irregular masses that have gradational contacts with anorthosite, gabbro or pyroxenite; (2) dike-like bodies in those rocks; and (3) small elongated bodies whose emplacement was guided by fracturing of anorthosite or gabbro. The titanomagnetite is also an important accessory mineral in much of the anorthosite, gabbro, and pyroxenite. The titanomagnetite was formed during the late stage of magmatic crystallization in which fluids and gases actively affect rock minerals already formed or still crystallizing (deuteric and pegmatitic stage). Most of the titanomagnetite crystallized before hot-water solutions became dominant in the later hydrothermal stage. The microscopic intergrowth of ilmenite and magnetite which makes up titanomagnetite of the western San Gabriel Mountains is so fine-grained that a complete mechanical separation of the two minerals is extremely difficult; this is an obstacle to concentrating the ore.

Mineralogy. Ilmenite, the ferrous titanium oxide ($FeTiO_3$), and rutile, the titanium oxide (TiO_2), are the only ore minerals of titanium.

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[13] Tucker, W. B., and Sampson, R. J., op. cit., p. 498.

[1] Moorhouse, W. W., Some titaniferous magnetites of the San Gabriel Mountains, Los Angeles County, California: Econ. Geology, vol. 33, pp. 737-748, 1938.
Oakeshott, G. B., Titaniferous iron-ore deposits of the western San Gabriel Mountains, Los Angeles County, California: California Div. Mines Bull. 129, pp. 245-266, 1948.

Ilmenite accounts for about 97 percent and rutile 3 percent of the titanium consumed in the United States. Other titanium minerals include sphene, perovskite, arizonite, brookite, pseudo-brookite, and octahedrite. Commercial "ilmenite" probably includes the mineral arizonite in some instances, and "rutile" may include brookite, octahedrite, and pseudo-brookite.

Localities. The only known region in California potentially capable of large titanium production is in the western San Gabriel Mountains in the area between Lang and Mt. Gleason. Here, about 36 ilmenite-magnetite deposits have been described. Some contain several million tons of titanomagnetite carrying from 5 to 20 percent TiO_2. Several concentrations of black ilmenite-magnetite sands are known in recent stream beds of the same area. Beach sands at Aptos, Santa Cruz County, and Redondo and Hermosa Beaches in Los Angeles County, are other possible commercial sources of titanium.

In 1926-27, titaniferous beach sands between Redondo and Palos Verdes in Los Angeles County were processed at an experimental plant in Hermosa Beach. The plant, designed for the manufacture of TiO_2, had a capacity of 1200 cubic yards per day. In the same years a similar experimental plant processed beach sands at Aptos in Santa Cruz County with the intention of producing sponge iron and titanium and chromium alloys. Neither project operated profitably, but experimentation has continued spasmodically under various operators to the present day.

Utilization.[2] Current trends in titanium technology emphasize its use in the paint and ceramic industries. Further advances in technology may lead to large-scale production of metallic titanium. Ninety-nine percent of the titanium ore mined is used in paints, enamels, and glazes which require white hiding (opaque) pigments. Titanium dioxide is an exceedingly opaque pigment and weathers and discolors less rapidly than other paint bases. Manufactured titanium dioxide, used almost wholly for pigments, consumed 99 percent of the total ilmenite tonnage in 1945-46. The balance was used largely in alloys and for making titanium carbide. Very small amounts were used in ceramics. In connection with the ceramic industry, TiO_2 has proved to be a good substitute for the expensive uranium oxide used in yellow glazes. It has also been used in the manufacture of other glazes and in the porcelain of artificial teeth because of its opaque "hiding" quality in thin coatings. It is sometimes used to lower the fusion point of clays.

Metallic titanium has long been used in certain steel alloys and has many properties which make it of industrial importance. It is very resistant to weathering, has great strength, is ductile, and is lighter than iron, although heavier than aluminum. The difficult and costly metallurgy of titanium has held back its use, but recent research by the U. S. Bureau of Mines has developed an economically practical method for large-scale production of titanium metal. In this process metallic titanium is obtained by reducing titanium tetrachloride with molten magnesium in the presence of helium. Production of the metal will probably increase in the next few years.

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[2] Meyer, H. M., and Bryson, R. L., Titanium: Minerals Yearbook 1946, pp. 1183-1191, 1948.
Meyer, H. M., Titanium: Eng. and Min. Jour., p. 89, Feb. 1949.

Annual production of titanium (ilmenite) in California.

Year	Tons	Value	Locality
1906	(Earliest attempted utilization of titaniferous iron ore) No production—Russ Siding, Los Angeles County		
1927-28	10,013	$150,195	Lang, Los Angeles County
1929-38	0	0	
1939-40	160	1,800	
1941-42	295	3,685	
1943-44	250	3,400	Hermosa Beach and Sand Canyon, Los Angeles County
1945	0	0	
1946	(Small tonnage)		Sand Canyon, Los Angeles County
1947	(Small tonnage)		Sand Canyon, Los Angeles County
1948	(Small tonnage)		Sand Canyon, Los Angeles County
Totals	10,718+	$159,080+	

Sixty-four percent of the rutile used in the United States in 1945-46 was for welding-rod coatings; production of alloys and titanium carbide used 15 percent; ceramic uses consumed one percent (72 short tons).

Markets. California, in 1948, did not produce titanium, other than a small amount of ilmenite from Los Angeles County, which was used as roofing granules. In the same year the United States produced a record 372,000 short tons and imported an additional 228,000 tons. The world's largest ilmenite producer was the National Lead Company mine at Tahawas, Essex County, New York. India contributed 177,600 tons of the ilmenite imported to the United States; and small amounts came from Norway and Canada.

Rutile production in the United States in 1948 was 7,100 tons; an additional 8,100 tons was imported from Australia. Domestic production was principally from Magnet Cove, Arkansas, and Roseland, Virginia.

Nominal price quotations on ilmenite, beginning September 15, 1948, were $18-$20 per ton of 56-59 percent TiO_2. The required TiO_2 percentage was slightly less than in previous quotations.

Nominal quotations for rutile have been 8 to 10 cents per pound for some years. The price is for guaranteed 94 percent TiO_2

History of Production.[3] Most production of titanium in California has come from Los Angeles County, although the beach sands near Aptos in Santa Cruz County were mined unsuccessfully years ago. The Los Angeles County production has come from sands of Redondo and Hermosa Beaches; from sands in Sand Canyon in the western San Gabriel Mountains, about 4 miles southwest of Lang Station; and from a massive titaniferous magnetite deposit 2.4 miles southwest of Lang. An attempt in 1906 to produce iron from titaniferous rock at Russ Siding in Soledad Canyon was abandoned when the presence of titanium and the refractory nature of the ore were recognized. In 1927-28, 10,013 tons of ilmenite were produced from the Lang locality and shipped to El Segundo for use in the manufacture of paint base. Abandonment of the project was forced by competition from less expensive foreign materials, particularly from ilmenite sands mined at Travancore, India. Since 1944, production of ilmenite in Los Angeles County has come mainly from ilmenite-magnetite

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[3] Tucker, W. B., Los Angeles field division—Los Angeles County: California Min. Bur. Rept. 28, pp. 287-345, 1927.

sands on the Live Oak and Ferro-Titan properties in lower Sand Canyon. At the Live Oak mine an electromagnetic mill is operated. The product has been sold as roofing granules and for weight in heavy rollers. It has also been sold to the San Gabriel Pigment Company at Roscoe, Los Angeles County, for the manufacture of an opaque pigment.

The E. I. DuPont Company conducted an extensive and systematic titanium prospecting program in the San Gabriel Mountains from 1927-38. At one time the company controlled a large number of claims in the area.

California titanium production has been insignificant compared with that of the United States and the rest of the world. Several of the ilmenite deposits of the San Gabriel Mountains contain 15 to 20 percent TiO_2 in estimated amounts that range from 300,000 to 6,000,000 tons. These may possibly support a large future production.

Production of ilmenite in the United States rose rapidly in the last few years to a high in 1948 of 372,000 short tons. The world's largest ilmenite mine is operated at Tahawas, Essex County, New York, by the National Lead Company. In 1949 the Du Pont Company will probably produce a large quantity of ilmenite from the sands near Starke, Florida. Other American production is coming from Finley, North Carolina, and from Roseland, Virginia. India has contributed most of the ilmenite imported to the United States. Smaller amounts have come from Canada, Norway, Brazil, Australia, and Ceylon. Canadian production will probably rise rapidly in 1949 when Kennecott Copper Corporation and New Jersey Zinc Company develop large ilmenite deposits in Quebec near Havre St. Pierre.

TUNGSTEN

By Richard M. Stewart

Commercial production of tungsten began in California in 1905. Since then deposits in the state have yielded a total of about 40,000 short tons of 60 percent WO_3 tungsten concentrates; this represents about a third of the nation's total output. The 1948 production of 1,767 short tons represented 44.1 percent of the United States' total and placed California as the leading tungsten producer in that year.[1] The Pine Creek mine in Inyo County has been the principal source in recent years and contains the largest known reserves of tungsten ore in the United States.

Mineralogy and Geologic Occurrences.[2] Tungsten does not occur free in nature and is a constituent of relatively few minerals. Of the 14 known tungsten-bearing minerals, those of commercial importance are ferberite ($FeWO_4$), wolframite [$(Fe,Mn)WO_4$], hübnerite ($MnWO_4$), and scheelite ($CaWO_4$). In these four minerals tungsten is the principal constituent. Scheelite and wolframite are the world's principal tungsten ore minerals. Ferberite is the principal tungsten mineral in Colorado's

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[1] Davis, H. W., Tungsten in 1948: U. S. Bur. Mines Mineral Industry Surveys, Mineral Market Reports MMS 1730, 1949.

[2] Hess, F. L., Tungsten minerals and deposits: U. S. Geol. Survey Bull. 652, 85 pp., 1917.

Hess, F. L., and Larsen, E. S., Contact metamorphic tungsten deposits of the United States: U. S. Geol. Survey Bull. 725-D, pp. 245-309, 1921.

Partridge, J. F., Tungsten resources of California: California Div. Mines Rept. 37, pp. 225-326, 1941.

Kerr, P. F., Tungsten mineralization in the United States: Geol. Soc. America Mem. 15, 241 pp., 1946.

most productive deposits; hübnerite is seldom found in commercial ore bodies.

Scheelite contains 80.6 percent WO_3 when pure, and is the principal tungsten mineral in California. It is most easily recognized by a light-blue fluorescence under ultra-violet light. Ferberite, wolframite, and hübnerite form an isomorphous series, the end members being ferberite and hübnerite. Intermediate members are generally called wolframite. These do not fluoresce. All of these tungsten minerals have high specific gravities.

Though tungsten deposits have formed under widely different conditions of temperature and pressure, they characteristically occur in or near acidic igneous rocks. Tungsten minerals are commonly scattered through igneous rocks, particularly pegmatites and aplite dikes; but few of these occurrences are of economic interest. Most commercial concentrations of tungsten have formed in veins and replacement bodies which are near igneous masses.

Most of the veins are rich in quartz and contain both scheelite and wolframite. In many of the high-temperature veins, the tungsten minerals are accompanied by cassiterite (SnO_2); in the medium- and low-temperature veins, such minerals as pyrite (FeS_2), chalcopyrite ($CuFeS_2$), sphalerite (ZnS), and galena (PbS) are commonly present. In the scheelite-rich quartz veins of the western United States, such as those at Atolia in California, wolframite is not present. Minor amounts of scheelite are present in the wolframite-quartz veins of Colorado and South Dakota.

Most of the tungsten mined in California in recent years has been obtained from contact-metamorphic deposits. Such deposits represent the replacement of calcareous rocks by minerals related in origin to an acidic igneous magma. The most common minerals of tungsten-bearing contact-metamorphic deposits are grossularite or andradite garnet, epidote, idocrase, and quartz; scheelite is by far the most abundant tungsten mineral. Many of these deposits in California, as elsewhere, contain appreciable amounts of molybdenite, and copper minerals.

As tungsten minerals are resistant to weathering and have relatively high specific gravities, they are readily concentrated in placer deposits. The wolframite placers of China have been the world's principal source of tungsten. The placer deposits of the Atolia district in California have been an important domestic source.

Localities. California, with the possible exception of Nevada, contains more tungsten localities than any other state.[3] Nearly all of these localities are confined to the areas intruded by the Sierra Nevada batholith and other igneous bodies related to it.[4] The distribution pattern of tungsten deposits is particularly dense near the east and west borders of the batholith from Kern and San Bernardino Counties northward to Madera and Mono Counties. Deposits are relatively sparse in the northern portion of the batholith, and are conspicuously absent in the Coast and Klamath Ranges. Throughout the tungsten-bearing belt metamorphosed sedimentary rocks, older than the batholith, extend into the igneous rocks as septa, or are completely surrounded by them. Most of the tungsten deposits have formed by contact metamorphism of calcareous portions of

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[3] Kerr, P. F., op. cit., p. 135.

[4] Jenkins, O. P., Outline geologic map of California, showing locations of tungsten properties; Economic mineral map of California no. 4—tungsten, scale 1:1,000,000, California Div. Mines, 1942.

the sediments. Others, such as those at Atolia, have formed as veins distinctly later than the enclosing granitic rocks.

Most of the tungsten produced in California has been obtained from two areas, the Atolia district in San Bernardino County and the Bishop district in Inyo County. The primary tungsten deposits in the Atolia district[5] are in a series of steeply dipping fissure veins containing high-grade scheelite ore in a quartz-carbonate gangue. Stibnite (Sb_2S_3) is abundant in a few of the veins. Pyrite (FeS_2) is a rare constituent of the veins but is abundant in the bordering portions of the country rock. Cinnabar (HgS) has been noted as a local constituent of the veins but is rare in the district. The veins, which are believed to be late Miocene in age, are in a late Jurassic (?) quartz monzonite. They have filled a series of roughly parallel fractures and contain the largest bodies of high-grade scheelite known in the United States. The known veins are confined to an area about 2 miles long and as much as 500 feet wide. Most of the production, however, has been obtained from a few veins.

The ore was deposited in open fissures with little wall-rock replacement and is believed to be epithermal. The scheelite occurs as shoots in the veins. The shoots are broadest near the surface and taper downward; they have an average stope length of about 100 feet and most are vertical. The grade of the ore has ranged from 1 to 15 percent WO_3, but has averaged about 4.1 percent. Locally, nearly pure scheelite was mined, some of which averaged 63 percent WO_3.

The Atolia veins are the source of the scheelite in two nearby placer areas. The placer area east of the vein deposits, which is known as the Spud Patch, has yielded most of the placer scheelite. Here the scheelite ranges in size from fine sand to fragments (''spuds'') weighing as much as several hundred pounds. The greatest scheelite concentrations are in well-defined channels which have been mined by underground methods and in later years by stripping and large open-pit operations. A placer area to the west of the vein deposits has been worked primarily for gold, but scheelite has been obtained as a by-product.

The tungsten deposits in the Bishop district are distributed along the eastern slope of the Sierra Nevada, and in the lower foothills called the Tungsten Hills. This district, which extends from Round Valley southward for about 20 miles, also includes the Pine Creek area to the west. This is one of the few areas in the world where scheelite occurs in commercial quantities in contact metamorphic deposits.

The Pine Creek mine contains the largest reserve of tungsten ore in the United States[6] and also produces molybdenum, copper, silver, and gold. The ore bodies are near the north end and on the west side of the Pine Creek pendant, an elongate block of metamorphic rocks surrounded by intrusive granite and quartz diorite. The pendant, 5½ miles long and 1 mile wide, is composed of hornfels, schist, and quartzite, with some marble along a 3½ mile section on the west side. There are five ore bodies in the Pine Creek mine and two in the adjoining Adamson mine. With the exception of one of the Adamson ore bodies, all of them are in the contact zone between the granite and the marble.

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[5] Hulin, C. D., Geology and ore deposits of the Randsburg quadrangle: California Min. Bur. Bull. 95, 1925.
Lemmon, D. M., and Dorr, J. V., Tungsten deposits of the Atolia district, San Bernardino and Kern Counties, California: U. S. Geol. Survey Bull. 922-H, 40 pp., 1940.

[6] Bateman, P. C., Pine Creek and Adamson tungsten mines, Inyo County, California: California Div. Mines Rept. 41, pp. 231-249, 1945.

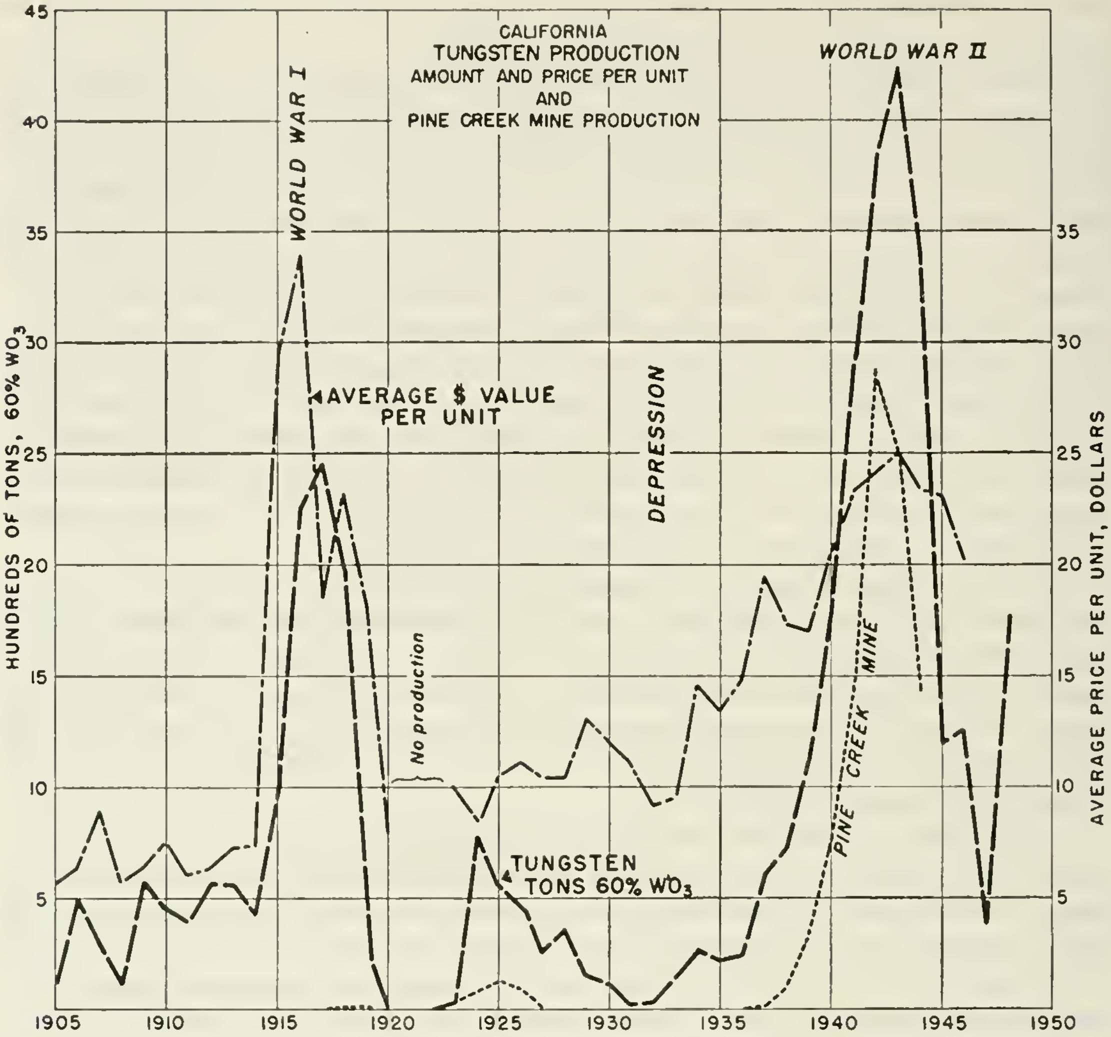

FIGURE 1. Chart showing amount of tungsten (60% WO_3) produced in California, 1905-48; average price per unit, 1905-46; production of Pine Creek mine, 1936-44.

This contact zone consists of a garnet-diopside tactite, quartz, and quartz-feldspar rocks. The tungsten ore shoots are restricted to the tactite and are sufficiently large and persistent to be mined individually. The average grade of ore mined and milled has been about 0.45 percent WO_3. These ore shoots, though outlined by assay values, have fairly sharp limits and are not bordered by large tonnages of marginal-grade ore. The localization of the ore shoots is thought to have been controlled by fracturing.

Scheelite is the only tungsten mineral. The molybdenum minerals are molybdenite and the secondary powellite [$Ca(Mo,W)O_4$], which may carry tungsten. Copper minerals, which carry silver and gold, are chalcopyrite and bornite.

Other deposits in the Bishop district have geologic settings similar to those of the Pine Creek area.[7]

Areas from which relatively small amounts of tungsten have been produced include the Posey Creek area, Tulare County; the Benton Range, Mono County; the region north of Kings River near the mouth of North Fork, Fresno County; the New York Mountains, San Bernardino County; the Kernville and Welden districts, Kern County; and the

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[7] Bateman, P. C., Erickson, M. P., and Proctor, P. D., Geology and tungsten deposits of the Tungsten Hills, Inyo County, California: California Jour. Mines and Geology, vol. 46, pp. 23-42, 1950.

Darwin district, Inyo County. The deposits of all of these areas, except those of the New York Mountains, are scheelite-bearing contact-metamorphic bodies. In the New York Mountains wolframite and hübnerite are disseminated in pegmatite dikes and quartz veins.

Utilization.[8] Tungsten is used principally in the manufacture of alloy steels, particularly the "high-speed" steels. Such steels retain their hardness even at red heat. High-speed steel tools will remain sharper and can take a heavier cut than tools of ordinary carbon steel. With such tools, the output per man and machine has been increased approximately five-fold. The alloy commonly used, the "18-4-1" type, contains 18 percent tungsten, 4 percent chromium, and 1 percent vanadium, plus 0.65 to 0.75 percent carbon.

Other products made of tungsten steels include hacksaw blades, cold chisels, razor and knife blades, armor plate and armor-piercing projectiles, drawing dies for wire manufacture, valve seats, and rails.

Tungsten is also used in the manufacture of cemented tungsten carbide, the hardest artificial substance in common use. Tungsten carbide is employed as inserts in rock bits, in cutting tools and in dies for drawing tungsten wire.

Stellite, a nonferrous cobalt-chromium-tungsten alloy, is very hard and corrosion resistant and is used for the same purposes as high-speed steels. Copper-tungsten and silver-tungsten alloys are used for welding electrodes and electrical contacts.

Tungsten, in rod, wire, or disc form, is one of the few metals used commercially in a very pure state. Such industrial tungsten usually has a purity of 99.95 percent plus, although minute amounts of impurities are added for special applications. Because of its high melting point (3400° C.), low vapor pressure, high tensile strength, and ductility, tungsten is used as filaments for incandescent electric lamps and radio tubes. Filament wire sizes range from 0.060 to 0.0003 inches in diameter. Though relatively small amounts of tungsten are consumed in the manufacture of filaments, no adequate substitute has been found for it in this use.

Tungsten is utilized in various chemical compounds, in dyes and paints, in fluorescent materials for x-ray photography, and in coloring agents in the manufacture of porcelains and stained papers.

Mining, Milling, and Metallurgy. Tungsten deposits are mined in the same way as similar deposits of other minerals. The use of the ultra-violet lamp for the recognition of scheelite is common as an aid in ore-grade control and to check mill efficiency.

Sliming of the naturally brittle tungsten minerals is the chief milling problem. In plants that depend upon gravity separation alone, slime losses are too high for economic tungsten recovery. Flotation in addition to gravity separation aids recovery but does not eliminate losses.

Tungsten concentrates are treated by rather complex chemical processes which produce sodium tungstate, tungstic acid, tungstic oxide, or ammonium paratungstate, all in a very pure state. These are reduced by either carbon or hydrogen in a controlled hydrogen atmosphere at tem-

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[8] Partridge, J. F., op. cit.
Sykes, W. P., Tungsten, in Mathewson, C. H., and others, Modern uses of nonferrous metals, pp. 376-388, Am. Inst. Min. Met. Eng., 1935.
Vanderburg, W. O., Tungsten, pt. 1: U. S. Bur. Mines Inf. Circ. 6821, 31 pp., 1935.

peratures from 1300° F. to 1900° F.[9] The particle size of the resulting metallic tungsten powder is important and can be controlled by the reducing time, nature of the charge, and the flow of hydrogen.

Either tungsten powder or ferrotungsten can be employed in the manufacture of high-speed steels. Ferrotungsten is prepared from tungsten powder by a thermite process. Ferrotungsten can also be prepared directly from high-grade ferberite concentrates, by means of carbon reduction with suitable fluxes.

Because of its very high melting point, tungsten metal is never melted in any of its processing. The powder-metallurgy techniques were originally developed to produce tungsten in a usable form. Tungsten rod is prepared by pressing blended lots of tungsten powder into small ingots. These are heat treated in two stages, at temperatures of approximately 2200° F. and 5500° F. The ingot can then be swaged at elevated temperatures to produce rod, which can further be swaged and drawn at high temperatures to produce wire and filament. This hot drawing must be at temperatures below the recrystallization temperature for tungsten, or about 1500° C.

Powder-metallurgy is also used to produce cemented tungsten carbide. Tungsten carbide powder is mixed with powdered cobalt, pressed into small bars and sintered in a reducing atmosphere.

Markets. In 1948 California tungsten mines, of which the Pine Creek mine was by far the largest producer, shipped 1767 short tons of concentrates (60 percent WO_3) which was 44.1 percent of the nation's total of 4005 tons.[10] Nevada and North Carolina followed California in that order.

The United States total was an increase over the 1947 total in spite of the 24 percent reduction in the tariff on tungsten ore and concentrates which went into effect May 22, 1948. The duty was reduced from $7.93 per short ton unit of WO_3 to $6.03 per unit.

Consumption of tungsten concentrates in the United States totaled 9300 tons; 4005 tons were produced domestically. Since 1910 the nation's tungsten production has been about 40 percent of consumption.[11]

Imports for domestic requirements in 1948 totaled 7963 tons of concentrates and were supplied principally by China, Korea, Brazil, and Bolivia, in that order.

The 1948 prices for tungsten ore and the various marketed tungsten products are given below.[12]

Tungsten powder	
98.8 percent minimum—1000 lb. lots	$2.90 per lb.
99 percent plus	$3.05–$3.15 per lb.
99.9 percent plus—hydrogen reduced	$4.50 per lb.
Ferrotungsten	
75–80 percent	$2.25–$2.35 per lb. of contained tungsten
Tungsten ore—price range during the year per short ton unit of WO_3	
Foreign, duty paid	$30.00 to $23.50
Domestic scheelite of good analysis, delivered, carload lots	$30.00 to $28.00

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[9] Schein, Sidney, and Forbes, J. W., The fabrication of tungsten wire: Wire and Wire Products, pp. 767-771, 836, Oct. 1947.

[10] Davis, H. W., op. cit.

[11] Lasky, S. G., and others, Tungsten, in Mineral resources of the United States, pp. 198-202, Washington, Public Affairs Press, 1948.

[12] Eng. and Min. Jour., Metal and Mineral Markets, vol. 19, New York, McGraw-Hill Publishing Company, Inc., 1948.

History of Production.[13] The first commercial tungsten production in California came from the Stringer district in eastern Kern County, south of Randsburg, in 1905. With the discovery of the Atolia district shortly afterward, California became an important tungsten producer. At this time the Colorado ferberite deposits were the nation's principal tungsten source, but in 1915, largely as a result of production from the Atolia district, California's tungsten output exceeded Colorado's.

The tungsten deposit of the Bishop district had been discovered by 1913, but the first recorded production was obtained in 1916. By 1918 several mines in this district were operating.

The peak production of this early period was reached in 1917 with a total of 2,466 tons of concentrates. After the war, prices fell and tungsten output slumped. During the period 1921-22 no tungsten was produced in the state. In 1922, when an import duty was levied on tungsten, production was resumed.

California's tungsten output increased to a high of 781 tons of concentrates in 1924 and then declined until 1933. Nevada became the leading producer in 1927. Except for a minor slump in 1935, production increased from 1933-43. In 1937 this increase was spurred by an increase in price, brought about by the rearmament program. It reached a high of 4,235 tons of concentrate in 1943. In the period 1943-47 production dipped sharply, but prices have continued high and in 1948 there was a marked upswing to approximately 1,700 tons of concentrates for the year.

Tungsten production reflects the eras of depression and prosperity and has been further affected by tariff, war, and preparation for war. The Atolia district was the principal producer in the state until 1938, when it was surpassed by the Bishop district.

URANIUM, THORIUM, AND RARE-EARTH ELEMENTS

By Charles W. Chesterman

The presence of minerals containing uranium, thorium, and the rare-earth elements has been known for many years. The requirements of the nation's atomic energy program have created an unprecedented demand for radioactive materials, and has stimulated widespread search for these materials throughout California and the entire United States. As a result of this search, a discovery of a potentially commercial deposit of the rare-earth mineral bastnäsite was made in San Bernardino County in 1949. Radioactive materials have been reported from numerous localities in California, but none has been exploited on a commercial basis.

Geological Occurrence. Most of the uranium, thorium, and rare-earth elements are obtained from three minerals: pitchblende (uraninite), black uranium dioxide containing some lead and varying amounts of rare-earth elements and thorium; carnotite, a yellow, earthy, hydrous potassium-uranium vanadate; and monazite, a honey-yellow phosphate of the cerium metals and rare-earth elements with varying amounts of thorium. A few of the less important minerals in this group include: Euxenite (a columbate and titanate of yttrium, erbium, cerium, and uranium), samarskite (columbate-tantalate of rare-earth elements),

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[13] Partridge, J. F., op. cit.

autunite (a hydrous phosphate of uranium and calcium), schroeckingerite (a hydrous carbonate and sulphate of uranium), torbernite (a hydrous phosphate of uranium and copper), thorianite (thorium dioxide—uranium may substitute in part for thorium), thorite (thorium silicate), and bastnäsite (a fluocarbonate of the rare-earth elements, especially cerium and lanthanum). Sphene and zircon often contain appreciable quantities of thorium.

Pitchblende occurs in veins, commonly with the sulphide minerals of silver, nickel, cobalt, and bismuth. Carnotite is the important secondary uranium mineral and occurs as local, irregular lenses in sandstone beds. It is also the cementing agent in the sandstone, and is often associated with fossilized logs. Monazite occurs commonly as a detrital mineral in placers, less commonly in pegmatites and gneisses.

Uraninite, the crystallized variety of pitchblende, has been reported to occur with gold in quartz veins at the Rathgeb mine, near San Andreas, Calaveras County.[1] Traces of monazite have been found in the black sands of Butte County; in the black-sand concentrates of the "Indian Diggins" district, and at Placerville, El Dorado County; at Michigan Bluff, Placer County; and in the Brownsville district, Yuba County. Monazite has also been reported as a heavy-mineral constituent of the black sands at Crescent City, Del Norte County, and at Trinidad, Humboldt County. In Riverside County it occurs in small crystals associated with xenotime and cyrtolite in pegmatites in the Southern Pacific silica quarry. Monazite also occurs in the pegmatites near Winchester; in pegmatites near the Jensen limestone quarry; and in pegmatites at Mesa Grande.

Recently, a discovery of a deposit containing bastnäsite, the only known potential source of the rare-earth elements in California, was made in eastern San Bernardino County near Mountain Pass. Bastnäsite is the most abundant mineral in a series of parallel, lenticular, steeply dipping veins. Barite, fluorite, siderite, limonite, copper and lead-bearing minerals, and other unidentified rare-earth minerals accompany the bastnäsite. The wall rocks are silicified acidic dikes and coarse augen gneisses and schists of pre-Cambrian age.

Small quantities of minerals containing uranium, thorium, and the rare-earth elements have been reported at other localities in the state. Torbernite and autunite have been found in rhyo-dacite at Summit Diggings, 6 miles north of Randsburg, Kern County. Black masses and crystals of allanite, a basic calcium aluminum iron silicate containing rare-earth elements, have been reported in pegmatites near Pala, San Diego County. Allanite has been obtained from rose-quartz bearing pegmatites northeast of Exeter, Tulare County. Cyrtolite with xenotime, samarskite, monazite, and yttrocrasite (?) occur in pegmatite at the Southern Pacific quarry near Nuevo, Riverside County.

Utilization. The uses of uranium and thorium are of two principal types: (1) energy, and (2) nonenergy uses. Most of the world's current output is used in the production of atomic-energy materials. Of the relatively small fraction consumed in nonenergy uses, the chemical industry consumes the largest part, particularly in the manufacture of uranium

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[1] Rickard, T. A., Certain dissimilar occurrences of gold-bearing quartz (with discussion by Philip Argall): Colorado Sci. Proc., vol. 4, pp. 323-339, 1895.

nitrate and acetate. The ceramic industry also uses uranium in manufacturing glass-to-metal contacts in vacuum tubes and in amber-colored glass for signal lights and lenses. Small amounts of uranium were used to tone motion picture film and to make negative-temperature-coefficient resistors.[2]

Thorium is used chiefly in the making of gas mantles. Minor amounts of thorium oxide are used in making special refractory crucibles and optical glasses. Metallic thorium is alloyed with tungsten to make electric light filaments.

Wide application is being made of the rare-earth elements. The largest single use for oxides and fluorides of the rare-earth elements is in cores of positive arc electrodes for floodlights and motion-picture projectors. Cerium master alloy (misch metal), containing about 40-52 percent cerium, 22-30 percent lanthanum, 15-17 percent neodymium, 8-10 percent prasedymium, yttrium, samarium, and other rare-earth metals, is diluted to 15-40 percent iron content and treated with other metals to make ferrocerium or ''sparking metal.'' This is used for sparking ''flints'' of cigarette lighters, miners' lamps, and other gas lighters. Cerium is an important constituent of some aluminum and magnesium alloys, to which it lends strength and hardness. Small amounts of cerium are used in ceramics, tanning, medicine, and optical glass.[3]

Markets. The principal sources of uranium in recent years were the Belgian Congo and Canada. The bulk of the thorium and rare-earth metals comes from monazite mined in Brazil, India, and Ceylon. But the imports of monazite into the United States from India and Brazil have been shut off, and the deposits of bastnäsite in San Bernardino County may well prove to be one of our most important domestic sources of thorium, and our only source of rare-earth metals.

In 1948 the Vanadium Corporation of America quoted the following post-war prices on uranium ores or concentrates, f.o.b., Naturita, Colorado:

U_3O_8 contained (percent)	Per pound of U_3O_8 contained
0.20-0.30	$0.35
0.31-0.40	.40
0.41-0.50	.50
0.51-1.00	.60
1.01-1.25	.70
1.26-1.50	.80
1.51-1.75	.90
1.76-2.00	1.00
2.01 and over	1.10

No price on uranium has been established. However, the Northern California Association of Scientists value refined uranium at $10 per pound.[4]

Monazite concentrates containing 65 percent total contained oxides of the rare-earth elements, including thorium oxide, are sold at $245 per metric ton.[5]

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[2] Matthews, A. F., Uranium and thorium: Minerals Yearbook 1946, pp. 1205-1224, 1948.

[3] Matthews, A. F., op. cit., pp. 1271-1272.

[4] Matthews, A. F., Uranium, radium, and thorium: Minerals Yearbook 1947, pp. 1199-1208, 1949.

[5] Eng. and Min. Jour., Metal and Mineral Markets, vol. 21, no. 1, New York, McGraw-Hill Publishing Co., Inc., Jan. 1950.

ZINC

By John C. O'Brien

Zinc produced in California has been obtained largely from two sources: mines in the desert regions of eastern California that are also sources of lead and silver, and copper-bearing deposits of the Sierran foothill belt and Shasta County. Since the first recorded production of zinc in 1906, approximately half of the state's total output of about 186 million pounds was obtained during the periods of relatively high prices induced by World Wars I and II. With less favorable price conditions, zinc production in the state has languished or stopped completely. In 1948, even though zinc prices were higher than in war-time, California's production of 5,325 short tons was the lowest since 1943 and represented less than one percent of the national total. The decline is attributable largely to depletion of developed reserves of the copper mines.

Mineralogy and Geologic Occurrence. Zinc and lead minerals ordinarily occur in close association and most of the world's output of zinc has been obtained from deposits similar to those described in the section on lead in this volume. Zinc and copper minerals are also commonly associated. Only rarely is zinc unaccompanied by either lead or copper. Sphalerite (ZnS), the only important primary ore of zinc, is present in nearly all types of sulfide deposits. Of the oxidized zinc minerals smithsonite ($ZnCO_3$) is the most common, and calamine ($H_2Zn_2SiO_5$) is also of commercial importance.

Replacement deposits are the principal sources of the world's zinc, but zinc mineralization is also common in fissure veins and other types of cavity fillings. Deposits of the world's greatest zinc district near Joplin, Missouri, represent selective hydrothermal deposition in Paleozoic limestones and dolomites.

Sphalerite commonly oxidizes to smithsonite which is relatively insoluble, but, in the presence of dilute sulfuric acid, sphalerite is dissolved and may not be redeposited. Instead the zinc may be dispersed in the ground water as a sulfate. Many deposits have, therefore, been leached of their zinc content. Carbonate rocks, however, act as a precipitant for descending zinc solutions and in this environment bodies of zinc carbonate and silicate ordinarily form below oxidizing lead deposits. The zinc bodies at the Cerro Gordo mine in Inyo County have had such an origin.

Localities. The principal zinc-bearing deposits of California are largely confined to two metallogenetic provinces. One is the copper-zinc belt which extends from Fresno County along the Sierran foothills to include districts in the Klamath Mountains of Shasta County. The other contains the lead-silver-zinc districts of the east-central portion of the state.

Of these, the copper-zinc mines have contributed most of the state's total zinc production. Many of the larger copper-bearing deposits of Shasta County and the Sierran Foothill belt contain sphalerite in significant amounts, but the copper ores of Plumas County are notably lean in zinc. The primary copper deposits of California are characteristically replacement deposits in igneous and metamorphic rocks. Their geological features have been summarized by Eric [1] and are briefly outlined in the section on copper in this bulletin.

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[1] Eric, J. C., Tabulated list of copper properties to accompany economic mineral map of California no. 6—copper: California Div. Mines Bull. 144, pp. 207-210, 1948.

The principal properties in Shasta County that have produced zinc are the Afterthought, Balaklala, Bully Hill, Richmond, Mammoth, and Rising Star mines. In the Sierran Foothill belt the important sources of zinc have been the Big Bend mine, Butte County; the Penn, Quail Hill, and Napoleon mines, Calaveras County; and the Blue Moon mine, Mariposa County.

The Darwin and Tecopa districts in Inyo County contributed most of the zinc produced in California in 1948. Zinc obtained from these districts is a by-product of lead-silver ores which contain small amounts of sphalerite and smithsonite.

The Cerro Gordo mine, in the Cerro Gordo district east of Lone Pine near the crest of the Inyo Range, was a significant zinc producer in the period 1911-15. The zinc ore was removed from bodies rich in sphalerite and smithsonite, which were developed largely after the depletion of the known reserves of the mine's lead-silver ore. Since 1917 the mine has been worked intermittently and on a small scale.

The ore bodies of all three areas formed in Paleozoic rocks. Their geological features are summarized in the section on lead in this bulletin.

Lead-zinc mineralization is also known in other Inyo County localities. Among these are the Resting Springs, Trona, Panamint, Ubehebe, and Wildrose districts. The Ubehebe district produced zinc in 1948.

In recent years zinc has been obtained from the Carbonate King and Mohawk mines of the Clark Mountain district, San Bernardino County. In this area, as in Inyo County, most of the lead-silver-zinc deposits occur along fractures in limestone.[2]

Small amounts of zinc have been shipped from the Silverado Canyon area of Orange County. Here, veins containing silver-bearing galena, sphalerite, and pyrite have formed in metamorphic rocks.[3]

Small amounts of zinc have also been obtained from copper-lead-zinc deposits in the Mineral King district of Tulare County.[4] These deposits contain chalcopyrite, pyrrhotite, pyrite, arsenopyrite, sphalerite, and galena, and occur along contacts between limestone and slate or granite.

In the period 1925-28 zinc was obtained from galena-sphalerite ores mined on Santa Catalina Island. The deposits are veins which have formed in metamorphic and volcanic rocks.[5]

Utilization.[6] In 1948 approximately 40 percent of the zinc consumed in the United States was used as a protective coating on steel, a process called galvanizing. It is estimated that 350,000 tons of zinc were used for galvanizing sheets, pipe, tubes, wires, and other articles in 1948.

The amount of zinc used in die casting has exceeded the amount used in brass products since 1946, and amounted to 220,000 tons or 26 percent of the 1948 production. A die casting is made by forcing molten metal into dies made of special iron or steel. Zinc-base die-casting alloys were developed which are stronger than zinc itself and have

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[2] Tucker, W. B., and Sampson, R. J., Mineral resources of San Bernardino County: California Div. Mines Rept. 39, pp. 474-492, 1943.

[3] Tucker, W. B., and Sampson, R. J., op. cit., pp. 122-123.

[4] Tucker, W. B., Mines and mineral resources of Tulare County: California Min. Bur. Rept. 15, pp. 947-954, 1916.

[5] Tucker, W. B., Mineral resources of Santa Catalina Island: California Min. Bur. Rept. 23, pp. 32-39, 1927.

[6] Ince, C. R., Zinc: Eng. and Min. Jour., vol. 150, pp. 79-80, 1949.

reduced the tendency of molten zinc to dissolve iron. In making zinc-base alloys, pure zinc is alloyed with copper, aluminum, and magnesium.

Brass products such as sheet, rod, wire, tube, castings, and other copper-base products used an estimated 100,000 tons of zinc in 1948. Rolling mills, zinc oxide, and miscellaneous uses accounted for about 26,000 tons. Zinc is rolled into thin sheets which are used in making flashlight batteries, roofing gutters, and flashings on houses and buildings. Zinc oxide is used in the manufacture of paint and rubber and for medicinal purposes.

Markets and Treatment of Ores. The rapid increase both in population and in industries in California has expanded the market for zinc. The 1945 production of 19,340,732 pounds of zinc in the state was about one-third of California's consumption. California zinc deposits are very seriously handicapped because all ores and concentrates must now be shipped out of the state for smelting and refining. A zinc smelter located in California would find a ready market for its product and would encourage the development of many zinc prospects now idle.

Most of the California zinc ores contain pyrite, and the zinc minerals are intimately associated with either chalcopyrite or galena. Therefore, they require costly fine grinding for satisfactory separation. All the ores carry some silver and some carry a little gold. Some of the carbonate ores of Inyo, Orange, and San Bernardino Counties are rich enough to ship without milling. All of the sulfide ores are concentrated by selective flotation to make a grade that can profitably be shipped to the smelter. In recent years zinc concentrates have been shipped to Great Falls, Montana.

California produced 19,340,732 pounds of zinc worth $2,224,184[7] in 1945 when the price of zinc was 8.25 cents per pound, but the production declined each year following, in spite of the price advance to 17½ cents per pound in November 1948. The 1948 production amounted to 5,325 short tons, worth $1,416,450. The decrease in production was caused by the depletion of reserves during the war.

History. Although the presence of sphalerite and smithsonite had been noted in the lead mines of Inyo County and Santa Catalina Island as early as 1884[8] the first production of zinc was recorded in 1906. In that year 206,000 pounds of zinc valued at $12,566 were produced in the state. In 1907 the large bodies of smithsonite were found in the footwall of the old lead stopes in the Cerro Gordo mine in Inyo County and 144,213 pounds of zinc valued at $8,598 were shipped from the county in that year. A production of 33,546 pounds from Orange County was also reported in 1907.

A relatively large amount of zinc carbonate ore had been shipped from Inyo County before zinc was obtained from the sphalerite of the copper ores in Shasta County. Zinc, though long recognized as a prominent constituent of numerous deposits was a detrimental material in the smelting of the copper ores. In 1915, the General Electric Company built a small experimental electrolytic zinc plant at Winthrop[9] and

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[7] Averill, C. V., and others, California mineral production for 1946: California Div. Mines Bull. 139, pp. 55-56, 1948.

[8] Hanks, H. G., California minerals: California Min. Bur. Rept. 4, pp. 368, 371, 1884.

[9] Tucker, W. B., Copper resources of Shasta County: California Min. Bur. Rept. 20, p. 423, 1924.

recovered 300 to 400 pounds of zinc per day. Some electrolytic zinc was produced from smelter fumes by the Mammoth Copper Company at Kennett in 1917 and 1918. In 1918 electrolytic zinc was also produced at Winthrop from raw ores obtained at the Afterthought and Bully Hill mines; but both of these electrolytic operations were apparently unprofitable.

The Bully Hill Mining Company built a 150-ton flotation plant at Winthrop in 1917; but it also was unsuccessful, as was a 300-ton flotation plant built by the Afterthought Mining Company at Ingot in 1918. Copper concentrates at the Ingot plant carried 12 percent zinc and the zinc concentrate carried 2.6 percent copper. At Bully Hill the Shasta Zinc Company built a reverberatory furnace and a zinc oxide plant which operated from June to December 1922, but these shut down because of the drop in the price of zinc oxide.

The California Zinc Company, when it took over the operation of the Afterthought and Bully Hill mines in 1924, abandoned the smelting operation and discontinued the production of zinc oxide. The flotation plant was remodeled and a bulk concentrate containing [10] 43 to 49 percent zinc, 3.7 to 4.1 percent copper, 7 to 11 percent iron, 1.3 to 1.7 percent lead, and 2.3 percent silica was obtained. This concentrate was shipped to Belgium for treatment.

A flotation plant was put into operation at White's Landing on Santa Catalina Island, Los Angeles County,[11] in December 1925, to treat the lead-zinc-silver ores mined at the Black Jack and Quarry mines. The concentrates were also shipped to Belgium for treatment.

The price of zinc dropped from 7.337 cents per pound in 1926 to 6.242 cents per pound in 1927, so that it was no longer profitable to ship zinc concentrates to Belgium. The zinc mines of Shasta County closed down in August 1927, and the Santa Catalina Island properties closed down early in 1928. Except for a flotation concentrate made as a by-product from the gold ore treated at the Spanish mine in Nevada County in 1931, California's production of zinc from 1928 to 1943 came from the carbonate ores of Inyo, Orange, and San Bernardino Counties.

The federal government premium plan for increasing the output of strategic minerals went into effect in 1942. Loans were also made available to develop and mine deposits of needed minerals. The number of California producers increased from four in 1942 to ten in 1943, and by 1945, selective flotation plants with a combined capacity of 800 tons per day were concentrating ores from the Big Bend mine in Butte County, the Penn mine in Calaveras County, the Richmond mine in Shasta County, and the Blue Moon mine in Mariposa County.[12] Zinc production rose from 16,390 pounds in 1939 to 19,340,732 pounds in 1945 and came from 12 mines in eight counties. The production was far in excess of development however, and by the end of 1945, both the Big Bend and the Blue Moon mines were shut down. The flotation plant at the Richmond mine operated until June 30, 1947, when the premium payments were stopped and the developed ore was exhausted. Production dropped to 5,325 short tons in 1948, but a new flotation plant of the Coronado Copper

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[10] Logan, C. A., Copper in California: California Min. Bur. Rept. 22, p. 376, 1926.

[11] Tucker, W. B., Mineral resources of Santa Catalina Island: California Min. Bur. Rept. 23, pp. 32-39, 1927.

[12] Bramel, H. R., Marketing and metallurgy of complex ores: California Div. Mines Bull. 144, p. 163, 1948.

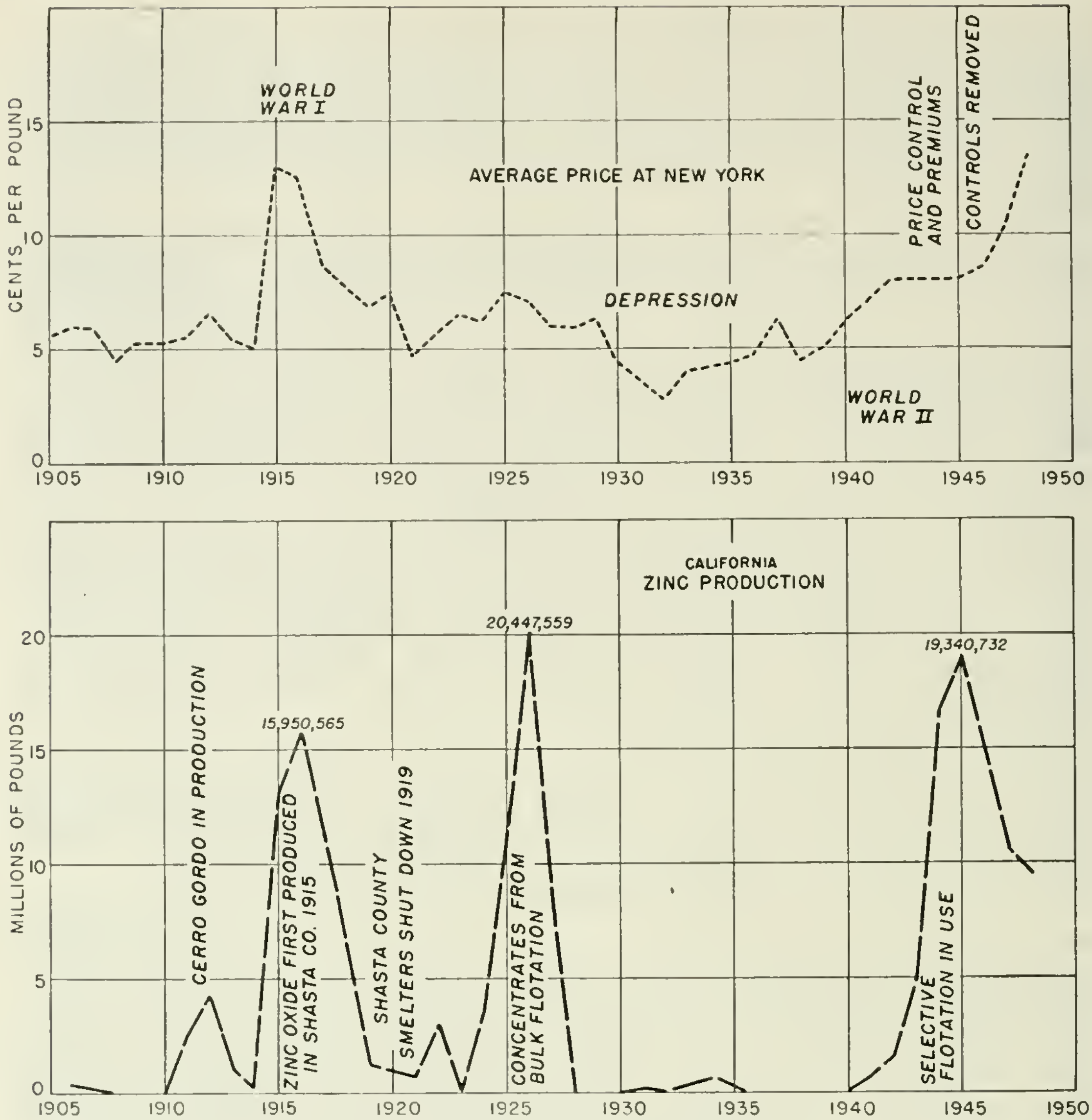

FIGURE 1. Chart showing production of zinc in California, and price of zinc in the United States, 1905-48.

and Zinc Company at the Afterthought mine in Shasta County began operation in October of that year. This plant, which has a capacity of 100 tons of ore per day, was built after the discovery of new zinc-copper bodies at the mine.

The experience gained in treating the complex zinc-copper ores of Shasta County and the recent studies and investigations made of the geology of sulfide ore bodies in California may result in the expansion of the zinc industry in the state.

ZIRCONIUM

By SAMUEL R. HOFFMAN

Zirconium and its compounds have attained wide usage in a great variety of industries. This metallic element is more abundant in the earth's crust than copper or lead and possesses many favorable characteristics which make it valuable in the metallurgical field.

Mineralogy and Geologic Occurrence. Zircon (zirconium silicate), the most widely distributed and the most abundant zirconium mineral, is a common constituent of many igneous and metamorphic rocks and of sands resulting from the disintegration of these rocks. Many sedimentary rocks contain zircon because the mineral is hard and chemically resistant to weathering. Baddeleyite (zirconium dioxide), much less widely distributed than zircon, is found in igneous rocks deficient in silica, and in gravels or sands derived from them. The high specific gravity of zirconium minerals leads to their concentration in alluvial deposits. Zircon and baddeleyite are the only zirconium-bearing minerals occurring in sufficient abundance to form deposits of commercial value. Zircon is a frequent constituent of black sands in which it may be distinguished from quartz by its brilliance, higher specific gravity, and insolubility in hydrofluoric acid. Ultraviolet light causes most specimens of zircon to fluoresce a brilliant orange, red, or yellow, a phenomenon which has been attributed to the presence of hafnium or uranium in the mineral.

Localities. Most of the world's supply of zircon has been produced from beach sands in Australia as a co-product of rutile, ilmenite, and monazite. Brazil has produced large quantities of baddeleyite from old gravels. India's output is obtained chiefly from the Travancore beach sands. Other countries producing zircon include Malaya, French Indo-China, Egypt, Italy, Korea, and Senegal. The entire production of zircon in the United States during recent years has come from Florida. Occurrences of zircon have been noted in many California placer deposits although only one has produced commercially to date. There are many potential sources awaiting further development of the market or technologic improvements for separating the component minerals in alluvial deposits.

Utilization. Flawless, transparent specimens of zircon are used as gemstones. Zirconium oxide is an important refractory and opacifier. Metallic zirconium is used in manufacturing ammunition primers, electrodes, photo-flash bulbs, flares, blasting caps, and welding rods for spot welding. Certain zirconium salt solutions render textiles water repellent. In steel-making, ferrozirconium acts as a deoxidizer and a scavenger. Zirconium is finding increasing application as an alloying element, tanning agent, and precipitant of various dyes, pigments, and color lakes.

Markets. The United States is the largest consumer of zircon and baddeleyite. Foreign imports are unloaded at northern Atlantic ports and are processed by several large chemical companies. The price of zirconium ore containing 65 percent zirconium oxide, delivered at the Atlantic seaboard and including the costs of insurance and freight, was quoted in January 1950 at $40 to $45 a short ton.[1] The current market quotation is more or less in line with prices obtained in former years.

Mining Methods and Treatment. Zircon is mined chiefly by sluicing and hydraulicking. The ore is concentrated by Wilfley tables or spiral concentrators. Electromagnetic and electrostatic operations separate the concentrate of heavy minerals. The zircon obtained is commonly heated in an arc furnace with carbon and the resulting product is burned in air or chlorine.[2] Metallic zirconium is produced by reducing zirconium oxide or zirconium chloride.[3]

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[1] Eng. and Min. Jour., Mineral Markets, vol. 21, no. 1, New York, McGraw-Hill Publishing Co., Inc., Jan. 1950.

[2] Blumenthal, W. B., Zirconium widens its industrial orbit: Chem. Industries, vol. 65, no. 5, pp. 728-730, November 1949.

[3] Jaffee, R. I., Zirconium metal, as of 1949: Jour. Metals, vol. 1, no. 7, pp. 6-9, July 1949.

History of Production. Small amounts of zirconium ore were produced in the United States as early as 1869 for use in incandescent gas mantles. In 1906 the discovery of large deposits of baddeleyite in Brazil gave impetus to the development of a zirconium industry. Production was erratic until improved metallurgical methods were developed after the first World War. World consumption of zirconium rose steadily and rapidly, Brazil and India supplying most of the raw material. In 1947 the United States imported more than 30,000 short tons of zirconium concentrates, of which Australia furnished 71 percent, Brazil 15 percent, and India 14 percent.[4]

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[4] Gustavson, S. A., Zirconium: Minerals Yearbook 1947, pp. 1262-1264, 1949.

PART V

DIRECTORY OF MINERAL PRODUCERS, DEALERS, AND COMMERCIAL LABORATORIES

CONTENTS

DIRECTORY OF PRODUCERS OF METALLIC AND NONMETALLIC MINERALS IN CALIFORNIA DURING 1948.

(Producers of natural gas and petroleum may be found in the Summary of Operations, California Oil Fields, July-Dec. 1948, vol. 34, no. 2, of the State Division of Oil and Gas.)

ANTIMONY

Mine	Operator	Address	Location of mine
Inyo County:			
Rocket	Carl Yackel	Trona	

ASBESTOS (TREMOLITE)

Operator	Address	Location of mine
Shasta County:		
Powhatan Mining Co.	Woodlawn, Baltimore, Md.	Hazel Creek
Loma Blanca Mines, Inc., Homer E. Fenn, Pres.	133 Katherine St., Salinas	Hazel Creek
Sylvester, Ray	Solari Hotel, Mount Shasta	Sims

BARITE

Operator	Address	Location of mine
Mariposa County:		
Baroid Sales Division, National Lead Co.	830 Ducommun St., Los Angeles	El Portal

BORATES

Operator	Address	Location of property
Inyo County:		
Pittsburgh Plate Glass Co., Columbia Chemical Division	Bartlett	Bartlett
United States Borax Co.	510 W. Sixth St., Los Angeles 14	Shoshone
Kern County:		
Pacific Coast Borax Co.	510 W. Sixth St., Los Angeles 14	Boron
San Bernardino County:		
American Potash and Chemical Corp.	3030 W. Sixth St., Los Angeles 54	Trona
West End Chemical Co.	608 Latham Square Bldg., Oakland 12	Westend

BROMINE

Operator	Address	Location of property
Alameda County:		
Westvaco Chemical Div., Food Machinery & Chemical Corp.	405 Lexington Ave., New York 17, N. Y.	Newark
San Bernardino County:		
American Potash and Chemical Co.	3030 W. Sixth St., Los Angeles 54	Trona

CALCIUM CHLORIDE

Operator	Address	Location of mine
San Bernardino County:		
California Rock Salt Co.	2436 Hunter St., Los Angeles 21	Amboy
Desert Properties Co., Frank Thomas, Receiver	374 Court St., Rm. 11, San Bernardino	Amboy
Hill Brothers Chemical Co.	2159 Bay St., Los Angeles 21	Amboy

CARBON DIOXIDE GAS

Operator	Address	Location of well
Imperial County:		
Cardox Western, Inc.	151 N. Avenue 19, Los Angeles 31	Niland
Mendocino County:		
Caldri Ice Corp.	Old River Road, Hopland	Hopland

CEMENT

Operator	Address	Location of mill
Calaveras County:		
Calaveras Cement Co.	315 Montgomery St., San Francisco 6	San Andreas
Kern County:		
Monolith Portland Cement Co.	215 W. Seventh St., Los Angeles 14	Monolith
Los Angeles County:		
Blue Diamond Corp.	1650 S. Alameda St., Los Angeles 54	Los Angeles
Riverside County:		
Riverside Cement Co.	621 S. Hope St., Los Angeles 14	Crestmore
San Benito County:		
Pacific Portland Cement Co.	417 Montgomery St., San Francisco 6	San Jaun Bautista
San Bernardino County:		
California Portland Cement Co.	612 S. Flower St., Los Angeles 14	Colton
Riverside Cement Co.	621 S. Hope St., Los Angeles 14	Oro Grande
Southwestern Portland Cement Co.	503 Roosevelt Bldg., 727 W. Seventh St., Los Angeles 14	Victorville
San Mateo County:		
Pacific Portland Cement Co.	417 Montgomery St., San Francisco 6	Redwood City
Santa Clara County:		
Permanente Cement Co.	Permanente	Permanente
Santa Cruz County:		
Santa Cruz Portland Cement Co.	324 Crocker Bldg., San Francisco 4	Davenport

CHROMITE

Mine	Operator	Address	Location of mine
Del Norte County:			
Tyson (French Hill)	Sam J. Wilson	Patricks Creek Tavern via Crescent City	Crescent City

CLAY

(Including producers of crude clay; and manufacturers of brick, tile, and other heavy clay products.)

Operator	Remarks*	Address	Location of plant or pit
Alameda County:			
California Pottery Co.	a, c	P.O. Box 68, Niles	Niles
N. Clark & Sons Division, Pacific Clay Products Co.	a, b	Box 145, Sta. A, Los Angeles 31	Alameda
Gladding, McBean & Co.	b, c	2901 Los Feliz Blvd., Los Angeles 26	Altamont, Livermore
Interlocking Roof Tile Co.	a, c	Box 488, Niles	Niles
Kraftile Co.	a, b, c	Niles	Niles
M. & S. Tile Co.	a, c	Decoto	Decoto
Tesla Sand & Clay Co., G. G. Sanders	c, f	Mills Bldg., San Francisco	Tesla
Amador County:			
N. Clark & Sons Division, Pacific Clay Products Co.	c	P.O. Box 145, Sta. A, Los Angeles 31	Ione
Gladding, McBean & Co.	c	2901 Los Feliz Blvd., Los Angeles 26	Ione
Western Refractories Co.	b, c	Russ Bldg., San Francisco	Ione
Calaveras County:			
California Pottery Co.	c	P.O. Box 68, Niles	Valley Springs
Contra Costa County:			
California Art Tile Corp.	a	27th and Main Sts., Richmond	Richmond
Gladding, McBean & Co.	b	2901 Los Feliz Blvd., Los Angeles 26	Pittsburg
Port Costa Brick Works, C. G. Berg, Pres.	b, c	Sixth and Berry Sts., San Francisco	Port Costa
Technical Porcelain & Chinaware Co.	a	Manila and Kearny Sts., El Cerrito	El Cerrito
United Materials & Richmond Brick Co., Ltd.	a, b	Box 7, Richmond	Richmond

CLAY—Continued

Operator	Remarks	Address	Location of plant or pit
Fresno County:			
Craycroft Brick Co.	a, b, c	P.O. Box 814, Fresno	Fresno
Humboldt County:			
Hindley Clay Products	a, b, c	3121 Essex St., Eureka	Cutten
Inyo County:			
Sierra Talc & Clay Co.	c	5509 Randolph Ave., Los Angeles 22	Olancha
Silicates Corp.	c	230 Park Ave., New York, N. Y.	Death Valley Junction
Kern County:			
American Mineral Co.	c	2770 E. Eighth St., Los Angeles 23	Cantil
Bakersfield Sandstone Brick Co.	b	315 E. 18th St., Bakersfield	Bakersfield
Hidecker Brick Co.	c	2500 E. Eighth St., Los Angeles	Fleta
Kernco Materials Co.	d	1916 Radiance Dr., Bakersfield	Muroc
King Lumber Co.	b	Box 1559, Bakersfield	Bakersfield
Macco Corp., Drilling Mud Div.	d	14409 S. Paramount Blvd., Paramount	Rosamond
McKittrick Mud Co.	d	Box 356, McKittrick	McKittrick
Mojave Corp.	d	P.O. Box 174, Los Nietos	Muroc
Los Angeles County:			
American Container Co.	a	3132 Washington Blvd., Los Angeles 23	Los Angeles
Angulo Tile Co.	a, c	19044 Kittridge St., Reseda	Reseda
Atkinson Brick Co.	b, c	13633 Central Ave., Los Angeles 2	Los Angeles
Atlas Sewer Pipe Co.	a, c	2309 S. Painter St., Whittier	Whittier
B. & W. Tile Mfg. Co.	a	14600 S. Western Ave., Gardena	Gardena
J. A. Bauers Pottery Co.	a	415 W. Ave. 33, Los Angeles	Los Angeles
J. C. Booth	a, c	1775 Stanford Ave., Santa Monica	Santa Monica
Builders Brick Co.	b, c	P.O. Box 266, Gardena	Compton
Coast Brick Co.	b, c	17720 Prairie Ave., North Torrance via Torrance	North Torrance
Davidson Brick Co.	b, c	4701 Floral Dr., Los Angeles 22	Los Angeles
General Refractories Co.	b	3363 Fruitland Rd., Los Angeles	Los Angeles
Gladding, McBean & Co., Tropico, L. A. & S. M. Plants	a, b, c	2901 Los Feliz Blvd., Los Angeles 26	Tropico, Los Angeles, Santa Monica, and Pico
Higgins Brick & Tile Works	b, c	P.O. Box 1125, Sta. A, Gardena	Moneta
Italian Terra Cotta Co.	a	1149 Mission Rd., Los Angeles	Los Angeles
Lynn Brick Co.	b, c	Normandie & Pacific Coast Hwy., Harbor City	Harbor City
Pacific Brick Co.	b, c	P.O. Box 1125, Sta. A, Gardena	Santa Monica
Pacific Clay Products	a, b, c	Box 145, Sta. A, Los Angeles 31	Los Angeles and Los Nietos
Pacific Tile & Porcelain Co.	a	P.O. Box 638, Hynes	Hynes
Pomona Brick Co., S. Bernard Strona	b, c	Ninth and Buena Vista, Pomona	Pomona

Pomona Tile Mfg. Co.	a	629 N. La Brea Ave., Los Angeles	Pomona
St. Louis Fire Brick & Insulation Co.	b	3050 E. Slauson St., Huntington Park	Huntington Park
San Valle Tile Kilns	a, c	1258 N. Highland Ave., Los Angeles 38	Reseda
Simons Brick Co., Walter R. Simons	b, c	1195 S. Boyle Ave., Los Angeles 23	Los Angeles
Southwest Brick Co.	b, c	17601 S. Western Ave., Los Angeles	Los Angeles
Tapper Brick & Tile Co.	a, b, c	4700 Ramona Blvd., Los Angeles 33	Los Angeles
Valley Brick & Supply Co.	b, c	6151 Kester Ave., Van Nuys	Van Nuys
Vernon Potteries	a	2300 E. 52d St., Los Angeles	Vernon
Marin County:			
McNear Brick Co.	a, b, c	McNear Point, San Rafael	McNear
Orange County:			
El Toro Clay Co., I. P. Arnold	c, f	7655 W. Second St., Downey, Los Angeles	El Toro
Gladding, McBean & Co.	c	2901 Los Feliz Blvd., Los Angeles 26	Irvine, Claymont, Prado
La Bolsa Tile Co.	a, c	R.F.D. 1, Box 175, Huntington Beach	Smeltzer
Placer County:			
Gladding, McBean & Co.	a, b, c	2901 Los Feliz Blvd., Los Angeles 26	Lincoln
Lincoln Clay Products Co.	c	P.O. Box 367, Lincoln	Lincoln
Riverside County:			
Alberhill Coal & Clay Co.	c	Box 4267, Village Sta., Los Angeles 24	Alberhill
Los Angeles Brick & Clay Products Co.	a, b, c	1078 Mission Rd., Los Angeles 54	Alberhill
Pacific Clay Products	c	Box 145, Sta. A, Los Angeles 31	Corona
Temescal Clay Co.	c	2569 Clarendon Ave., Huntington Park	Temescal
Sacramento County:			
Cannon & Co.	a, b, c	Box 802, Sacramento 4	Ben Ali and Michigan Bar
Gladding Bros., Mfg. Co.	c	S. Third and Keyes St., San Jose 12	Folsom
H. C. Muddox, Jessie E. Muddox, Owner	a	30th and L Sts., Sacramento	Sacramento
Panama Pottery Co.	a	R.F.D. 4, Box 1478, 24th St. Rd., Sacramento	Sacramento
Sacramento Brick Co.	b, c	1300 Front St., Sacramento 4	Sacramento
San Benito County:			
San Benito Bentonite Co.	e	111 Brookside Ave., San Jose	Tres Pinos
San Bernardino County:			
Baroid Sales Div., National Lead Co.	d, e	830 Ducommun St., Los Angeles	Hector
Gladding, McBean & Co.	c	2901 Los Feliz Blvd., Los Angeles 26	Goff
Hancock Brick Yard, C. P. Hancock & Son	b, c	Box 421 Riverside	Highgrove
Inerto Co.	●	1489 Folsom St., San Francisco	Newberry
Marter Mining Co.	c	530 W. Sixth St., Los Angeles 14	Bryman

CLAY—Continued

Operator	Remarks	Address	Location of plant or pit
San Bernardino County—continued:			
Louis Martinez	e	Box 374, Red Mountain	Red Mountain
Southern California Minerals Co., W. K. Skeoch	c	320 S. Mission Rd., Los Angeles 33	Goff
Taft, E. Warner	d	P.O. Box 316, Rosamond	Barstow
San Diego County:			
Filtrol Corp.	e	634 S. Spring St., Los Angeles 14	Palm Siding
La Jolla Canyon Clay Products	a, c	P.O. Box 712, La Jolla	La Jolla
Union Brick Co.	b, c	P.O. Box 356, San Diego 9	Rose Canyon
Vitrified Products	a, c	4570 Pacific Highway, San Diego 10	San Diego
San Joaquin County:			
Pacific Clay Products Co.	a, c	Box 145, Sta. A, Los Angeles	Stockton
San Joaquin Brick Co.	b	P.O. Box 387, Stockton 4	Roberts Island
Stockton Brick & Tile Co.	a	P.O. Box 547, Stockton	Stockton
San Luis Obispo County:			
San Luis Brick Works	b, c	2900 S. Broad St., San Luis Obispo	San Luis Obispo
Santa Barbara County:			
McNall Building Materials	a, b	P.O. Box 758, Santa Barbara	Santa Barbara
Santa Clara County:			
Garden City Pottery	a	560 N. Sixth St., San Jose	San Jose
Gladding Bros. Mfg. Co.	a, b, c	S. Third and Keyes Sts., San Jose 12	San Jose
Myers Ceramic Pottery, F. Hinz	a	Box 97, Santa Clara	Santa Clara
Remillard-Dandini Co.	b, c	321 13th St., Oakland	San Jose
Stanislaus County:			
Lester Raggio	c	Knights Ferry	Cooperstown
Sutter County:			
Gladding, McBean & Co.	c	2901 Los Feliz Blvd., Los Angeles 26	Nicolaus
Tulare County:			
S. P. Brick & Tile Co.	b, c	P.O. Box 568, Fresno	Exeter
Ventura County:			
Rocklite Products	c	1800 N. Ventura Ave., Ventura	Ventura
Shell Oil Co., Dent Clay Pit	d	Shell Bldg., San Francisco	Ventura

a. Clay products. b. Brick and hollow building-tile. c. Crude clay. d. Oil-well drilling mud. e. Filtering clay and bentonite. f. Fire sand.

COAL

Operator	Address	Location of mine
Amador County:		
American Lignite Products Co.	Ione	Ione

COPPER

Principal copper producers in California in 1948. (Not less than 10,000 pounds.)

Mine	Operator	Address	Postoffice of mine
El Dorado County:			
Pioneer-Lilyama	Morning Star Mining Corp.	650 S. Grand St., Los Angeles	Coloma
Inyo County:			
Darwin group	Anaconda Copper Mining Co.	25 Broadway, New York, N. Y.	Darwin
Pine Creek	United States Vanadium Corp.	30 E. 42d St., New York, N. Y.	Bishop
Santa Rosa	Santa Rosa Mining Co., et al.	Box 116, Keeler	Keeler
Shoshone group	Anaconda Copper Mining Co.	25 Broadway, New York, N. Y.	Tecopa
Madera County:			
Daulton	L. M. Bradford	Box 207, Madera	Daulton
San Bernardino County:			
Bagdad-Chase	Donald F. Love	Ludlow	Ludlow
Mohawk	Mohawk Mines, Inc.	Nipton	Nipton
Shasta County:			
Afterthought	Coronado Copper and Zinc Co.	1206 Pacific Mutual Bldg., Los Angeles	Ingot
Iron Mountain-Hornet-Richmond	The Mountain Copper Co., Ltd.	216 Pine St., San Francisco	Matheson

DIATOMITE (DIATOMACEOUS EARTH)

Operator	Address	Location of mine or quarry
Inyo County:		
Hazen Mining Co.	Independence	Zurich
Los Angeles County:		
Great Lakes Carbon Corp., Dicalite Division	612 S. Flower St., Los Angeles 14	San Pedro
Santa Barbara County:		
Johns-Manville Products Corp.	22 E. 40th St., New York 16, N. Y.	Lompoc

DOLOMITE

Operator	Address	Location of quarry
Inyo County:		
Inyo Marble Co., D. H. Dunn, Pres.	726 E. 29th St., Los Angeles	Keeler
Monterey County:		
Permanente Metals Corp. (name changed to Kaiser Aluminum and Chemical Corp. on Nov. 28, 1949)	P.O. Box 1531, Salinas	Natividad
San Benito County:		
Westvaco Chemical Division, Food Machinery & Chemical Corp.	Newark	Hollister
San Bernardino County:		
Marter Mining Co.	530 W. Sixth St., Los Angeles 14	Thorn
Tuolumne County:		
U. S. Lime Products Corp.	1840 E. 25th St., Los Angeles 25	Sonora

FELDSPAR

Operator	Address	Location of mine
Kern County:		
N. W. Sweetser	Box 445, Rosamond	Rosamond
San Bernardino County:		
Gladding, McBean & Co.	2901 Los Feliz Blvd., Los Angeles	Atolia

GOLD

Principal gold producers in California out of a total of 436 placer operators and lode mines in 1948. (Not less than 100 ounces.)

Mine	Type of mine*	Operator	Address	Postoffice of mine
Amador County:				
Alpine Plant	i	Alpine Gravel Plant	Star Rt. No. 2, Jackson	Jackson
Argonaut	o	Argonaut Mining Co., et al.	Jackson	Jackson
Belden	a	Belden Amador Mines, Inc.	Box 28, Fort Wayne, Indiana	Pine Grove
Hageman	a	DRD Mining Co., and Dowdel Bros.	Pioneer	Pioneer
Kennedy Tailings	d	F. L. Shevlin and Frank Fuller	Jackson	Jackson
Lilly Dredge	h	Ernest L. Lilly	1640 E. Poplar St., Stockton	Plymouth
Old Eureka	a	Central Eureka Mining Co.	111 Sutter St., San Francisco	Sutter Creek
Butte County:				
Butte Unit	f	Yuba Consolidated Gold Fields	351 California St., San Francisco	Hammonton
Kister Dredge	f	Gold Hill Dredging Co.	351 California St., San Francisco	Oroville
Lancha Plana No. 5	f	Lancha Plana Gold Dredging Co.	La Lomita Rancho, Lockeford	Chico
Calaveras County:				
Blackstone	a	Blackstone Mine	907 Pierce St., Albany	West Point

GOLD—Continued

Mine	Type of mine*	Operator	Address	Postoffice of mine
El Dorado County:				
Cosumnes	a	Cosumnes Mines, Inc.	Grizzly Flats	Grizzly Flats
Long Bar	h	El Dorado Placers Mining Corp.	Georgetown	Folsom
Pioneer-Lilyama	a	Morning Star Mining Corp.	311 S. Grand St., Los Angeles	Coloma
Shaw	a	Volo Mining Co.	464 Main St., Placerville	Placerville
Fresno County:				
Rockfield Plant	i	Pacific Coast Aggregates, Inc.	400 Alabama St., San Francisco	Friant
Imperial County:				
Padre & Madre	a	Holmestake Mining Co.	Ogilby (via Winterhaven)	Ogilby
Inyo County:				
Darwin and Shoshone groups	m, l	Anaconda Copper Mining Co.	25 Broadway, New York, N. Y.	Darwin, Tecopa
Kern County:				
Kern Placers	h	Foley Bros., Inc.	90 S. Oak Knoll Ave., Pasadena	Randsburg
Standard	a	Earl Blickenstaff, et al.	Rosamond	Rosamond
Tropico, et al.	a	Burton Bros.	Rosamond	Rosamond
Lassen County:				
Hayden Hill	a	Lassen Eagle Co.	c/o Silver Dollar Mining Co., Wallace, Idaho	Adin
Los Angeles County:				
Largo Plant	i	Consolidated Rock Products Co.	Box 2950 Terminal Annex, Los Angeles	Azusa
Madera County:				
Heiskell Property		Ernest Noble, et al.	Raymond	Raymond
Mariposa County:				
Dredge No. 3	h	Thurman & Wright	235 Montgomery St., San Francisco	Hornitos
French	a	Gold Ridge, Inc.	Bagley	Bagley
Mount Gaines	a	Mount Gaines Mining Co.	Hornitos	Hornitos
Schroeder Group	a	Schroeder Mines	Midpines	Midpines
Upper Bear Creek	h	James H. Henry	706 Don Burton Bldg., Stockton	Mariposa
Merced County:				
Merced Dredge No. 1	f	Merced Dredging Co.	1805 Mills Tower, San Francisco	La Grange
Midstate Dredge	h	Midstate Equipment & Dredging Co.	Box 781, Modesto	Le Grand
Snelling Dredge	f	Snelling Gold Dredging Co.	Snelling	Snelling

Modoc County:				
Moonlight	a	Moonlight Mine	230 S. E St., Lakeview, Oregon	New Pine Creek (Ore.)
Nevada County:				
Ancho & Erie Groups	a	Ancho-Erie Mining Co.	401 Second St., San Francisco	Graniteville
Empire Star, et al.	a	Empire Star Mines Co., Inc.	Box 1027, Grass Valley	Grass Valley
Gaston	a	Tonopah Divide Mining Co.	15 E. First St., Reno, Nevada	Nevada City
New Brunswick-Idaho Maryland	a	Idaho Maryland Mines Co.	368 Russ Bldg., San Francisco	Grass Valley
Relief Hill	g	A. P. Landsburg and Ernest Massera, leasing from Western Gold Co.	Star Rt., Nevada City 942 Mills Bldg., San Francisco	North Bloomfield
Spring Hill	a	Spring Hill Corp.	1911 Mills Bldg., San Francisco	Grass Valley
Placer County:				
Doty Ravine	r	Schwartz and Mitchell	Roseville	Lincoln
Mary Len	a	Mary Len Mine	Newcastle	Newcastle
Virginia Town Dredge	h	Virginia Town Placer Mine	1177 Pacific Ave., San Francisco	Lincoln
Plumas County:				
First Chance	h	R & M Mining Co.	Strawberry Valley	Strawberry Valley
Sacramento County:				
Capital Dredge	f	Capital Gold Dredging Co.	351 California St., San Francisco	Fair Oaks
Cosumnes Dredge	f	Cosumnes Gold Dredging Co.	456 California St., San Francisco	Sloughhouse
Dredge No. 4	f	Thurman and Wright	235 Montgomery St., San Francisco	Sloughhouse
Fair Oaks Plant	i	Fair Oaks Gravel Co.	Rt. 1, Box 533, Fair Oaks	Fair Oaks
General Dredge	h	General Dredging Co.	Natoma	Natoma
Lancha Plana No. 4	f	Lancha Plana Gold Dredging Co.	La Lomita Rancho, Lockeford	Folsom
Natomas Dredges	f	Natomas Co.	Box 1197, Sacramento	Natoma
Van Vleck Property	h	Mountain Gold Dredging Co.	Sutter Creek	Michigan Bar
San Bernardino County:				
Bagdad-Chase	a	Donald F. Love	Ludlow	Ludlow
Kelly	c	Frank Royer	Randsburg	Randsburg
Spud Patch	p	Surcease Mining Co.	Box 786, Sacramento	Red Mountain
San Joaquin County:				
Lower Comanche	f	Gold Hill Dredging Co.	311 California St., San Francisco	Camanche
Upper Comanche	f	Gold Hill Dredging Co.	311 California St., San Francisco	Camanche
Shasta County:				
Iron Mountain-Hornet-Richmond	n, o & q	The Mountain Copper Co., Ltd.	216 Pine St., San Francisco	Matheson
Lincoln Dredge	h	Lincoln Gold Dredging Co.	Box D, Lincoln	Redding
Thurman Dredge	f	Thurman Gold Dredging Co.	235 Montgomery St., San Francisco	Redding
Williamson Property	h	Roy S. Olson	1178 Walnut Ave., Redding	Buckeye
Yankee John	a	Igo Mining Co., et al.	Redding	Redding

GOLD—Continued

Mine	Type of mine*	Operator	Address	Postoffice of mine
Sierra County:				
Brush Creek	a	Alfred L. Merritt	453 Scenic Ave., Piedmont	Goodyear Bar
Gold Point	a	Best Mines Co.	Downieville	Downieville
Original 16 to 1 Mine	a	Original Sixteen to One Mine, Inc.	1611 Russ Bldg., San Francisco	Alleghany
Siskiyou County:				
Indian Creek	h	French Gulch Dredging Co.	307 Russ Bldg., San Francisco	Fort Jones
Reeves Ranch Dredge	f	Reeves Ranch Dredging Co.	Happy Camp	Happy Camp
Scandia	h	Scandia Mines	5261 Stockton Blvd., Sacramento	Horse Creek
Siskiyou Unit	f	Yuba Consolidated Gold Fields	351 California St., San Francisco	Callahan
Yreka Dredge	f	Yreka Gold Dredging Co.	220 Montgomery St., San Francisco	Seiad Valley
Stanislaus County:				
La Grange No. 4	f	La Grange Gold Dredging Co.	1805 Mills Tower, San Francisco	La Grange
Tuolumne Dredge	f	Tuolumne Gold Dredging Co.	1 Sansome St., San Francisco	La Grange
Trinity County:				
Brown Bear	a	Brown Bear Gold Mines, Inc.	French Gulch	Lewiston
Indian Creek	h	Terminal Truck Service	211 N. 16th St., Sacramento	Douglas City
Junction City Dredge	f	Junction City Mining Co.	Junction City	Junction City
Kelly	a	Thomas Kelly Co.	Hayfork	Hayfork
Long Bar	h	Thomson Divide Mining Co.	Box 525, Redding	Lewiston
Mires & Garner Dredge	f	Mires & Garner	Redding	Coffee Creek
Oak Hill, et al.	f	The Goldfield Consolidated Mines Co.	1 Montgomery St., San Francisco	Junction City
Rex	g	Perry T. Bennett	Weaverville	Weaverville
Swanson	g	Salyer Syndicate	1528 Russ Bldg., San Francisco	Salyer
Tuolumne County:				
Eagle Shawmut	d	Louis Warnken, Jr.	Chinese Camp	Chinese Camp
Ford	e	Ralph & Joe Tapley	Box 356, Columbia	Columbia
Hidden Treasure	e	Hidden Treasure Mine	Box 51, Columbia	Columbia
Street	a	Hayward Corp.	914 Union Nat'l Bank Bldg., Houston, Texas	Jamestown
Yuba County:				
Blue Point	g	Rose Bar Development Co.	311 California St., San Francisco	Smartsville
Yuba Unit	f	Yuba Consolidated Gold Fields	351 California St., San Francisco	Hammonton

* a. Lode gold mine
b. Silver mine
c. Gold-silver mine
d. Tailings dump
e. Pocket mine
f. Dredge (bucket line)
g. Hydraulic mine
h. Dragline dredge
i. Sand and gravel plant
j. Suction dredge
k. Lead mine
l. Zinc mine
m. Zinc-lead mine
n. Pyrite mine
o. Terminal cleanup
p. Tungsten mine
q. Leaching operation
r. Dryland dredge
s. Zinc-lead-copper mine

GRANITE

Operator	Address	Location of quarry
Fresno County		
Superior-Academy Granite Co.	Clovis	Academy
Lassen County		
Greig Quarry, J. B. Wagender	805 Weatherlow St., Susanville	Susanville
Los Angeles County		
H. A. Jones, et al	215 W. Green St., Pasadena	Saugus
Placer County		
Union Granite Co.	Rocklin	Rocklin
San Bernardino County		
Texas Quarries, Inc.	Box 605, Victorville	Victorville
San Diego County		
California Black Granite Co.	Rt. 1, Box 248J, Escondido	Twin Oak Valley
California Cut Stone & Granite Works	Railroad Ave. at Magnolia, South San Francisco	Vista
Fred B. Clemens	3460 Imperial Ave., San Diego	Suncrest
Crystal Black Quarry, John Stridsburg	Box 115, Escondido	Spooks Canyon
Lakeside Silver Gray Granite Co.	Lakeside	Lakeside
National Quarries	Rt. 2, Box 185, Escondido	Escondido & Fall Brook
Pacific Cut Stone & Granite Co.	414 S. Marengo Ave., Alhambra	Escondido
Southern California Granite Co.	3845 Imperial Ave., San Diego 2	Foster
Valley Granite Co., W. T. Blackwood	243 E. Fifth St., Escondido	Escondido
San Luis Obispo County		
R. A. Mora	358 N. Broad St., San Luis Obispo	San Luis Obispo

GYPSUM

Operator	Address	Location of quarry
Alameda County		
Westvaco Chemical Division, Food Machinery & Chemical Corp. (Output not included in production figures as gypsum is by-product of chemical process using minerals already included in state total.)	405 Lexington Ave., New York, N. Y.	Newark
Fresno County		
Agricultural Mineral & Fertilizer Co., A. D. Sousa	P.O. Box 832, Los Banos	Los Banos
John K. Griffin	270 Upland Dr., San Francisco 7	Tumey Gulch
Super Gypsum Mine	P.O. Box 66, Chowchilla	Dos Palos
Valley View Gypsum Mine	Rt. 4, Box 221, Madera	Firebaugh
Imperial County		
F. J. Pearl	153 N. Willow Ave., Baldwin Park	Bertram
U. S. Gypsum	300 W. Adams St., Chicago 6, Ill.	Plaster City
Kern County		
Carrisa Gypsum Mine, C. L. Fannin	Rt. 1, Box 7, Wasco	Wasco
H. M. Holloway	Box 310, Lost Hills	Lost Hills
McKittrick Agricultural Gypsum Co.	McKittrick	McKittrick
Pacific Gypsum Co., W. D. Fowler	P.O. Box 563, Bakersfield	Conner
Western Gypsum Co.	Wasco	McKittrick
Kings County		
H. M. Holloway	Box 310, Lost Hills	Avenal
Riverside County		
United States Gypsum Co.	300 W. Adams St., Chicago, Ill.	Midland
Utah Construction Co.	1 Montgomery St., San Francisco	Inca Siding
San Luis Obispo County		
C. E. Vanderford Gypsum Mine	Shandon	Shandon
Ventura County		
Monolith Portland Cement Co.	215 W. Seventh St., Los Angeles 14	Quatal Canyon

IODINE

Operator	Address	Mine
Los Angeles County		
Deepwater Chemical Co., Ltd.	Box 588, Compton	Compton
The Dow Chemical Co.	Midland, Michigan	Long Beach, Venice, and Seal Beach

IRON

Mine	Operator	Address	Location of mine
Riverside County			
Eagle Mountain	Kaiser Co., Inc.	P.O. Box 217, Fontana	Desert Center
San Bernardino County			
Cave Canyon	Mineral Materials Co.	1145 Westminster Ave., Alhambra	Baker
Vulcan	Kaiser Co., Inc.	P.O. Box 217, Fontana	Kelso

LEAD

Principal lead producers in California in 1948. (Not less than 10,000 pounds.)

Mine	Operator	Address	Postoffice of mine
Inyo County—continued:			
Cerro Gordo	Enterprise Mining Corp.	Beverly Hills	Keeler
Custer	L. D. Foreman & Co.	850 S. Fourth West St., Salt Lake City, Utah	Keeler
Darwin Group	Anaconda Copper Mining Co.	25 Broadway, New York, N.Y.	Darwin
Defense	Foreman & Skinner	850 S. Fourth West St., Salt Lake City, Utah	Panamint Springs
Empress Group	Joe McCully	Box 53, Darwin	Darwin
Gold Bottom-Ophir	Damon & Damon	1612 Orange St., Redding	Trona
Lane-Eagle	L. D. Foreman & Co.	850 S. Fourth West St., Salt Lake City, Utah	Keeler
Lippincott	George Lippincott	Box 1811, Santa Ana	Panamint Springs
Minnietta	Finley & Vignich	Panamint Springs Resort, Lone Pine	Panamint Springs
Queen of Sheba-Carbonate	New Sutherland Divide Mining Co.	958 Mills Bldg., San Francisco	Death Valley
Quinn	Bert Quinn	Cartago	Cartago
Reward (Brown Monster)	T. L. Bright, et al.	Lone Pine	Independence
St. Charles	Porter Ryan Mining Corp.	Box 395, Lone Pine	Lone Pine
Santa Rosa	Santa Rosa Mining Co.	Box 116, Keeler	Keeler
Shoshone Group	Anaconda Copper Mining Co.	25 Broadway, New York, N.Y.	Tecopa
Surprise	Foreman & Skinner	850 S. Fourth West St., Salt Lake City, Utah	Panamint Springs
Ubehebe	Ubehebe Mines, Inc.	Box 111, Beatty, Nevada	Panamint Springs
San Bernardino County			
Blue Buzzard	John W. Ballance & B. L. Whitney	Nipton	Nipton
Carbonate King	O. B. DeWitt	Nipton	Nipton
Carbonate King Zinc	Crystal Cave Mining Co. (J. Q. Little)	Nipton	Nipton
Eagle Lead	Eagle Lead Corporation	Los Angeles	Indio
Mohawk	Mohawk Mines, Inc.	Nipton	Nipton
Wilshire	Altana Corp., et al.	Nipton	Nipton
Shasta County			
Afterthought	Coronado Copper & Zinc Co.	1206 Pacific Mutual Bldg., Los Angeles	Ingot

LIME, LIMESTONE, AND SHELLS

Operator	* Product	Address	Location of quarry
Alameda County			
Westvaco Chemical Division, Food Machinery & Chemical Corp.	a, d	405 Lexington Ave., New York, N.Y.	Newark
El Dorado County			
Auburn Lime Products Co.	a, b, f	Box 231, Auburn	Newcastle
California Rock & Gravel Co.	b	1800 Hobart Bldg., San Francisco	Newcastle
Diamond Springs Lime Corp.	a, b, c	Box 409, Diamond Springs	Diamond Springs
El Dorado Limestone Co., J. H. Bell, Pres.	b	Shingle Springs	Shingle Springs
Inyo County			
Blue Star Mines, Ltd.	b	Rm. 510, 810 S. Spring St., Los Angeles	Zurich
Monterey County			
The Permanente Metals Corp. (Name changed to Kaiser Aluminum & Chemical Corp. on November 28, 1949)	a	P.O. Box 1531, Salinas	Moss Landing
San Bernardino County			
Cal. Portland Cement Co.	a, b	612 S. Flower St., Los Angeles 14	Colton
Chubbuck Lime Co., Charles I. Chubbuck	a, b, c	4711 Worth St., Los Angeles	Chubbuck
Marter Mining Co.	b	530 W. Sixth St., Los Angeles	Lucerne Valley
Riverside Cement Co.	b	621 S. Hope St., Los Angeles	Oro Grande
Victorville Lime Rock Co.	b	Box 548, Victorville	Victorville
West End Chemical Co.	a, b	608 Latham Sq., Oakland 12	Westend
San Mateo County			
Pacific Portland Cement Co.	c, d	417 Montgomery St., San Francisco	Redwood City
Rockaway Quarry, Inc.	e	340 Pine St., San Francisco 4	Rockaway Beach
Ken Royce, Inc.	e	185 Bayshore Blvd., San Francisco 24	Rockaway Beach
Santa Clara County			
Permanente Cement Co.	b	Permanente	Permanente

LIME, LIMESTONE, AND SHELLS—Continued

Operator	*Product	Address	Location of quarry
Santa Cruz County			
Henry Cowell Lime and Cement Co.	a, b	2 Market St., San Francisco	Santa Cruz
Pacific Limestone Prod. Co.	b, c	Spring St., Santa Cruz	Santa Cruz
Santa Cruz Portland Cement Co.	b	Crocker Bldg., San Francisco	Davenport
Siskiyou County			
Electro Lime and Chemical Corp.	b, c, e	536 SE Sixth Ave., Portland, Oregon	Gazelle
Tuolumne County			
Sonora Marble Aggregates Co.	b	356 Church St., San Francisco	Sonora
U. S. Lime Products Corp.	a, b, c	1840 E. 25th St., Los Angeles 11	Sonora
Ventura County			
Western Lime Products Co.	b, c	6305 Yucca St., Los Angeles	Santa Susana

* a. Producer of burnt lime
b. Industrial limestone
c. Agricultural lime
d. Shells
e. Crushed limestone
f. Used in rough construction

LITHIA

Operator	Address	Location of mine
San Bernardino County		
American Potash & Chemical Corp.	3030 W. Sixth St., Los Angeles 54	Trona

MAGNESIA AND OTHER MAGNESIUM COMPOUNDS

Operator	Product	Address	Location of plant
Alameda County:			
The Paraffine Cos., Inc.	Carbonate	Emeryville 8	Emeryville
Westvaco Chemical Division, Food Machinery & Chemical Corp.	Oxide	405 Lexington Ave., New York 17, N. Y.	Newark
Monterey County:			
The Permanente Metals Corp. (name changed to Kaiser Aluminum & Chemical Corp., in November, 1949)	Oxide	P.O. Box 1531, Salinas	Moss Landing
San Diego County:			
Westvaco Chemical Division, Food Machinery & Chemical Corp.	Chloride	405 Lexington Ave., New York 17, N. Y.	Chula Vista
San Mateo County:			
Johns-Manville Products Corp.	Basic carbonate	22 E. 40th St., New York 16, N. Y.	Redwood City
Marine Magnesium Prod. Corp., R. E. Clarke	Carbonate, hydroxide, and oxide	South San Francisco	South San Francisco

MAGNESITE

Operator	Address	Location of mine
Santa Clara County:		
Westvaco Chemical Division, Food Machinery & Chemical Corp.	405 Lexington Ave., New York 17, N. Y.	Red Mountain

MERCURY (QUICKSILVER) *

Mine	Operator	Address	Location of mine
Del Norte County:			
Shults Bros. (Patricks Creek)	I. N. & M. D. Shults	Box 127, Medford, Ore.	Patricks Creek
Lake County:			
Great Western	Bradley Mining Co.	Crocker Bldg., San Francisco 4	Middletown
Sulphur Bank	Bradley Mining Co.	Crocker Bldg., San Francisco 4	Clearlake Park
Napa County:			
Knoxville	Geo. E. Gamble (owner)	Monticello	Monticello
San Benito County:			
Aurora	R. Diaz	Idria	Idria
Juniper	Berg & Sciochetti	P.O. Box 637, Hollister	Panoche
New Idria	New Idria Quicksilver Mining Co.	Mills Bldg., San Francisco	Idria
San Luis Obispo County:			
Buena Vista	J. E. Wyatt	Adelaide St., Paso Robles	Paso Robles
La Libertad	Moapa Mining Co.	Box 325, Paso Robles	Cambria
Santa Clara County:			
New Almaden Dump	Almaden Dumps	Almaden	Almaden
Sonoma County:			
Mt. Jackson	Sonoma Quicksilver Mines, Inc.	58 Sutter St., San Francisco	Guerneville
Yolo County:			
Reed	Bradley Mining Co.	Crocker Bldg., San Francisco 4	Rumsey

* Excluding names of a few small mines for which no data were available other than those obtained from purchasers.

MINERAL PIGMENTS, NATURAL

Operator	Address	Location of property
San Bernardino County: Rowe, Mullinix and Buehler	1555 Sunset Ave., Pasadena 3	Ludlow

MOLYBDENUM

Operator	Address	Location of mine
Inyo County: U. S. Vanadium Corp.	30 E. 42d St., New York 17, N. Y.	Bishop

PEAT

Operator	Address	Location of bog
Contra Costa County: California Peat Co.	P.O. Box K, Antioch	Antioch
Modoc County: Modoc Peat Moss Co.	604 Mission St., San Francisco	Likely
Orange County: Lawrence P. Kraemer	Box P, Placentia	Westminster
San Diego County: Growers Peat Humus Co.	P.O. Box 486, Oceanside	Oceanside

PEBBLES FOR GRINDING

Operator	Address	Location of pit
San Diego County:		
Crystal Silica Co.	717 E. 61st St., Los Angeles	Encinitas Beach

PERLITE

Operator	Address	Location of quarry
Napa County:		
National Perlite Co.	Kennedy Road & S. P. R. R., Campbell	St. Helena

PLATINUM GROUP METALS

Operator	Address	Location of deposit
Butte County:		
Gold Hill Dredging Co.	311 California St., San Francisco	Oroville
Mariposa County:		
Thurman & Wright	960 Russ Bldg., San Francisco	Hornitos
Merced County:		
Merced Dredging Co.	1805 Mills Tower, San Francisco	La Grange
Snelling Gold Dredging Co.	Snelling	Snelling
Sacramento County:		
Capital Gold Dredging Co.	351 California St., San Francisco	Fair Oaks
General Dredging Co.	Natoma	Natoma
Thurman & Wright	960 Russ Bldg., San Francisco	Sloughhouse
San Joaquin County:		
Gold Hill Dredging Co.	311 California St., San Francisco	Camanche
Shasta County:		
Thurman Gold Dredging Co.	960 Russ Bldg., San Francisco	Redding
Siskiyou County:		
Reeves Ranch Dredging Co.	Happy Camp	Happy Camp
Yreka Gold Dredging Co.	220 Montgomery St., San Francisco	Seiad Valley
Yuba County:		
Yuba Consolidated Gold Fields	351 California St., San Francisco	Hammonton

POTASH

Operator	Address	Location of plant
San Bernardino County:		
American Potash and Chemical Co.	3030 W. Sixth St., Los Angeles 54	Trona

PUMICE AND VOLCANIC ASH

Operator	Product*	Address	Location of property
Amador County:			
Chas. Bacon	b	Ione	Carbondale
Calaveras County:			
Brownlite Products	a	701 Laurel St., Modesto	Valley Springs
Jack Grant	a	Vallecito	Vallecito
Contra Costa County:			
Pittsburg Pumice Works	a	Rt. 1, Box 21, Pittsburg	Pittsburg
Inyo County:			
Desert Materials Corp.	a	6371 Wilshire Blvd., Los Angeles 36	Inyokern
Petty Pumice Products	b	Box 21, Inyokern	Dunmovin
Western Talc Co.	b	1901 E. Slauson Ave., Los Angeles 11	Shoshone
H. A. Van Loon	b	Bishop	Bishop
Kern County:			
Insulpum Corp.	a	P.O. Box 451, Mojave	Cantil
Madera County:			
California Industrial Mineral Co.	b	Friant	Friant
Elmer Erickson	a	Star Rt., Box 1, Fresno 7	Friant

Modoc County:			
Glass Mt. Brick Co.	a	Box 10, Star Rt. 2, Tulelake	Glass Mountain
Glass Mt. Volcolite Co., H. W. Free	a	Tionesta	Glass Mountain
Miers & Renstrom	a	Tionesta	Glass Mountain
William Stanley	a	Tionesta	Glass Mountain
Mono County:			
Insulating Aggregate Co., G. M. M. Grant	a	Bishop	Laws
U. S. Pumice Supply Co.	a, c	5509 Randolph St., Los Angeles 22	Leevining
H. A. Van Loon	a	Bishop	Benton
Napa County:			
Basalt Rock Co.	a	P.O. Box 540, Napa	Napa
Pearl Pumice Co.	a	2186 Monticello Rd., Napa	Napa
Walker Pumice Co.	a	Monticello Rd., Napa	Napa
San Bernardino County:			
Western Talc Co.	a	1901 E. Slauson Ave., Los Angeles 11	Yermo
Williams Bros.	b	611 Sunset St., Azusa	Hinkley
San Luis Obispo County:			
Chandler & Lewton	b	Santa Margarita	Creston
Siskiyou County:			
Boorman Pumice Products	a	Tionesta	Glass Mountain
Glass Mt. Industries	a, c	P.O. Box 766, Klamath Falls, Ore.	Glass Mountain
Glass Mt. Volcolite Co., H. W. Free	a, c	Tionesta	Glass Mountain
John Madsen, (Skoria Star Brick Co.)	a, c	P.O. Box 711, Klamath Falls, Ore.	Glass Mountain
Thompson Pumice Co.	a	Tionesta	Glass Mountain
Stanislaus County:			
Cro-Diatomite, Inc.	b	822 12th St., Modesto	Newman

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[*] a. Pumice. b. Pumicite or volcanic ash. c. Scoria.

PYRITE

Operator	Address	Location of mine
Shasta County:		
The Mountain Copper Co., Ltd., L. T. T. Kett, Mgr.	216 Pine St., San Francisco	Matheson

QUICKSILVER—see MERCURY

SALT

Operator	Address	Location of plant
Alameda County:		
American Salt Co.	341 Broadway, San Francisco 11	Mt. Eden
Leslie Salt Co.	310 Sansome St., San Francisco	Newark and Mt. Eden
Morton Salt Co.	310 S. Michigan Ave., Chicago, Illinois	Newark
Oliver Bros. Salt Co.	Mt. Eden	Mt. Eden
Kern County:		
Long Beach Salt Co.	2476 Hunter St., Los Angeles 21	Saltdale
Mono County:		
C. C. Miller	837 W. Los Angeles St., P.O. Box 365, Baldwin Park	Leevining
Monterey County:		
Monterey Bay Salt Works, E. C. Vierra, Mgr.	Box 43, Moss Landing	Moss Landing
Orange County:		
The Irvine Co.	Box B, Tustin	Newport Beach
San Bernardino County:		
California Rock-Salt Co.	2436 Hunter St., Los Angeles 21	Amboy
Dale Chemical Industries, Inc.	P.O. Box 319, Twenty-nine Palms	Twenty-nine Palms
San Diego County:		
Western Salt Co.	1245 National Ave., San Diego	Chula Vista

SAND, GRAVEL, AND STONE, MISCELLANEOUS

Under the heading of "miscellaneous stone" are four divisions—crushed rock, grinding mill pebbles, paving blocks, and sand and gravel. Crushed rock includes crushed rock that is used in macadam, ballast, andfor concrete; also rock used for rubble and riprap.

Note—The California State Highway Commission, the various counties, cities, U. S. Engineers, U. S. Bureau of Reclamation, U. S. Forest Service, U. S. National Park Service, and U. S. Bureau of Public Roads produce both crushed rock and sand and gravel in various places in the state used in construction and maintenance of highways, but not specified in this listing.

Operator	Product*	Address	Location of pit or quarry
Alameda County:			
California Rock & Gravel Co.	a	1800 Hobart Bldg., San Francisco	Livermore
Heafey-Moore Co., Leona Quarry	b	344 High St., Oakland	Oakland
Inland Aggregates Co., Inc.	a	P.O. Box 236, Niles	Niles
Henry J. Kaiser Co.	a, b	Kaiser Bldg., 1924 Broadway, Oakland	Radum
Leslie Salt Co.	b	310 Sansome St., San Francisco	Newark
J. L. Martin	b	5921 Shepherd Canyon Rd., Oakland	Oakland
Pacific Coast Aggregates, Inc.	a, b	400 Alabama St., San Francisco	Eliot and Centerville
San Leandro Rock Co.	b	1575 Lake Chabot Rd., San Leandro	Lake Chabot
Tesla Sand & Clay Co., G. G. Saunders	c	Mills Bldg., San Francisco	Tesla
W. C. Thompson, Inc. (Concrete Materials Co.)	a	1401 Illinois St., San Francisco	Pleasanton
A. C. Zaro	a	Box 323, Pleasanton	Pleasanton
Amador County:			
Chas. Ayres	a	P.O. Box 266, Sutter Creek	Sutter Creek
Frederickson Bros.	b	1259 65th St., Emeryville	
Butte County:			
Butte Creek Rock Co.	a	Centerville Rd., Chico	Chico
Henry J. Kaiser Co.	a, b	1924 Broadway, Oakland	Oroville
Calaveras County:			
Neilsen Sand & Gravel Co.	a	Box 14, San Andreas	San Andreas
Colusa County:			
Cortina Sand, Gravel and Silt; Gene Godin	a	Colusa	Colusa
Contra Costa County:			
Antioch Sand Co.	a	1806 30th Ave., San Francisco 22	Antioch
N. M. Ball Sons	a	685 Delaware, Berkeley	Walnut Creek
Basalt Rock Co.	a	Eighth and River Sts., Napa	Antioch

SAND, GRAVEL, AND STONE, MISCELLANEOUS—Continued

Operator	Product*	Address	Location of pit or quarry
Contra Costa County—continued:			
Blake Bros., Anson Blake	b	Box 1002, Richmond	Point Richmond
Henry J. Kaiser Co.	a, b	1924 Broadway, Oakland	Antioch and Upton
Marchio Sand Co.	e	Antioch	Antioch
Morris Sand Pit, Ben Morris	a	R.F.D. Box 100, Antioch	Antioch
Roberts Sand Co.	e	Box 323, Pittsburg	Nortonville
Serra Bros.	b	R.F.D. Rt. 1, Box 355, Martinez	Walnut Creek
Del Norte County:			
Basalt Rock Co., Inc.	b	Eighth and River Sts., Napa	
El Dorado County:			
Diamond Springs Lime Co.	b	Diamond Springs	Diamond Springs
Fresno County:			
Atchison, Topeka & Santa Fe Railway Co.	a, b, g	121 E. Sixth St., Los Angeles 14	Oakhurst, Piedra
Central Rock & Sand Co.	a	Sanger	Sanger
Herndon Rock Products Co.	a, b	410 Thorne St., P.O. Box 886, Fresno	Herndon
Pacific Coast Aggregates, Inc.	a, b	400 Alabama St., San Francisco	Rockfield
Sharp & Fellows Construction Co.	b	533 Central Bldg., San Francisco	
Southern California Edison Co.	a, b	Edison Bldg., Los Angeles 53	
Thompson Materials & Construction Co., Inc.	a, b	Avenal	Avenal
Glenn County:			
E. B. Bishop & Edward Thomas dba Orland Sand & Gravel Co.	a	P.O. Box 469, Orland	Orland
Southern Pacific Co.	a	65 Market St., San Francisco	Wyo
Humboldt County:			
Tom Hull	a	Eureka	Hoopa
Mercer Fraser Co., Inc., Essex & Fernbridge	a	Second and Commercial Sts., Eureka	Arcata and Fortuna
Northwestern Pacific R. R. Co.	a	San Rafael	Sequoia
Imperial County:			
Ranco Construction Co.	a	Box 1328, Brawley	Brawley
Valley Transit Cement Co.	a	El Centro	El Centro
Yuma Sand & Gravel Co.	a	1144 W. Eighth St., Yuma, Arizona	Winterhaven

Inyo County:			
Bishop Engineering & Construction Co.	a	Bishop	Bishop
Inyo Marble Co.	a	728 E. 29th St., Los Angeles 11	Lone Pine
Mt. Whitney Rock Products, G. L. Watterson	a	Lone Pine	Lone Pine
Kern County:			
Edison Sand Co.	a	Box 395, Sta. A, Bakersfield	Bakersfield
Griffith Co.	a	Bakersfield	Bakersfield
Hartman Concrete Materials	a	P.O. Box 1632, Bakersfield	Bakersfield and Maricopa
Kern Rock Co., Ltd.	a, b	P.O. Box 1697, Bakersfield	Kern River
Lake County:			
Aggrelite Co., John C. McFayden	b	1734 Webster St., Oakland	
Dariel Camp Rock Co.	a	Calistoga	Middletown
Evans Bros.	a	Kelseyville	Kelseyville
Lange Bros. Sand and Gravel Plant, H. Lange & A. Lange	a	Lakeport	Kelseyville
Lassen County:			
Grayson & Spurgeon	a, b	1512 Fourth St., Susanville	Susanville
Los Angeles County:			
Arrow Rock Co.	a	2815 Glendale Blvd., Los Angeles 26	Monrovia and Roscoe
A. T. & S. F. R. R., I. L. Hibbard, Gen. Mgr.	a	121 E. Sixth St., Los Angeles 14	Forbes
Guy F. Atkinson	b	P.O. Box 259, Long Beach	
Azusa Rock & Sand Co.	a, b	P.O. Box 175, Azusa	Azusa
Richard R. Ball	a, b	Box 96, Walteria	Walteria
Blue Diamond Corp., Ltd.	a	1650 S. Alameda St., Los Angeles	El Monte and Roscoe
Wm. J. Bonfield	g	2008 Laurel Canyon Rd., Los Angeles	Hollywood
Chandler Sand & Gravel, L. Chandler	a	Lomita	Lomita
City Rock Co.	a, b	P.O. Box 8, Sunland	Sunland
Consolidated Rock Products Co.	a, b	Box 2950 Terminal Annex or 2730 S. Alameda St., Los Angeles	Los Angeles, Azusa, Roscoe, Monrovia, Baldwin Park, and North Hollywood
Gordon Transfer Co.	a	907 Main St., El Segundo	El Segundo
Graham Bros., Inc.	a	2000 N. Peck Rd., El Monte	El Monte
Granite Materials Co.	a	P.O. Box 368, Roscoe	Roscoe
John D. Gregg	a, b	Box 110, Whittier	Roscoe
Hanawalts	b	Box 187, La Verne	Pomona
Lindauer Corp.	a	Box 337, La Habra	La Habra
Livingston Truck & Materials Co.	g	3366 Cherry St., Long Beach 7	Rolling Hills
Los Angeles Decomposed Granite Co.	g	Montebello	Montebello
Manning Bros. Rock & Sand Co.	a, b	Irwindale	Irwindale

SAND, GRAVEL, AND STONE, MISCELLANEOUS—Continued

Operator	Product*	Address	Location of pit or quarry
Los Angeles County—continued:			
Mission Rock & Sand Co.	a	P.O. Box 215, Upland	San Gabriel
Owl Rock Products Co.	a	420 S. Alameda St., Compton	Monrovia
Pacific Rock & Gravel Co.	a, b	P.O. Box 30, Arrow Highway, Monrovia	Monrovia
Santa Catalina Island Co.	b	Box B-2, Avalon	Pebble Beach
Edward Sidebotham & Sons, Inc.	a	751 E. L St., Wilmington	Lomita
Madera County:			
Thompson Materials & Construction Co.	a	Avenal	
Marin County:			
Basalt Rock Co.	b	Eighth and River Sts., Napa	McNear Point
Hutchinson Co.	b	Box 156, El Cerrito	San Rafael
Marin Gravel Co.	a	Box 11, Point Reyes Sta.	Point Reyes
Mendocino County:			
John Burman & Sons	a	2750 Harrison Ave., Eureka	Fort Bragg
Ford Gravel Co., Kirby Ford	a	Ukiah	Ukiah
John Freitas, Ukiah Gravel & Cement Co.	a	Ukiah	Ukiah
Williams & Baxman	a	Fort Bragg	Fort Bragg
Merced County:			
Cressy Sand & Gravel Plant, Vernon & Milton Lustre	a	Rt. 2, Box 360, Merced	Cressey
J. C. Halbert, Merced S. & G. Co.	a	Winton	Winton
Los Banos Gravel Co.	a	Los Banos	Los Banos
River Rock Co.	a	435 15th St., Merced	Merced
Turlock Rock Co.	a	Turlock	Ballico
Modoc County:			
Great Northern Railway Co.	a, e	Klamath Falls, Ore.	Mammoth and Malin
Monterey County:			
Del Monte Properties Co., C. S. Olmsted	a, b, c	Del Monte	Pacific Grove
H. W. Kalar	a	Marina	Marina
Monterey Sand Co.	a, h	Box 928, Monterey	Seaside
M. J. Murphy, Inc.	a	P.O. Box 100, Carmel	Carmel
Pacific Coast Aggregates, Inc.	a	400 Alabama St., San Francisco	Lapis and Prattco
Napa County:			
Basalt Rock Co.	b	Eighth and River Sts., Napa	Napa
Benson Gravel Plant	a	Angwin	Pope Valley
Juarez Quarry, M. G. Reidenbach	b	Napa	Napa
Z. Tomczak	a	St. Helena	St. Helena

Nevada County:			
Frederickson Bros.	b	1259 65th St., Emeryville	
Orange County:			
I. P. Arnold	b	7655 E. Second St., Downey	Santa Ana
Geo. T. Calhoun	a	P.O. Box 1741, Santa Ana	Anaheim
California Rock Co.	a	Yerba & Chapman, Orange	Orange
Consolidated Rock Products Co.	a, b	2730 S. Alameda St., Los Angeles	Fullerton and Orange
Foster Sand & Gravel Co.	a	915 S. Spadra Rd., Fullerton	Orange
A. E. Fowler & Sons	a	Rt. 1, Box 19-A, Orange	Orange
Graham Bros., Inc.	a	2000 N. Peck Rd., El Monte	San Juan Capistrano
D. D. Lawhead & Sons	a, g	Seal Beach	Seal Beach and Buena Park
McClellan & Son	a	Anaheim	Anaheim
Sully-Miller Construction Co.	a	1500 W. Seventh St., Long Beach	El Modena
Placer County:			
Union Granite Co., Ruhkala Bros.	b	Rocklin	Rocklin
Riverside County:			
A. T. & S. F. Ry. Co.	b	121 E. Sixth St., Los Angeles 14	Box Springs
Guy F. Atkinson Co.	b	1103 Heartwell Bldg., Long Beach	Bly Junction
Calavera Materials Co.	b	P.O. Box 8, Winchester	Winchester
Emil Johnson	b	Rt. 2, Box 185, Escondido	Perris
Massey Rock & Sand Co.	a	Indio	Indio
Mission Indians	a	Palm Springs	Palm Springs
Palm Springs Bldrs. Supply Co.	a	Palm Springs	White Water
San Gorgonio Rock Products	a, b	P.O. Box 1414, Banning	Banning
Service Rock Co.	a	Box 309, Riverside	Riverside
Transit Mixed Concrete Co.	a	3464 E. Foothill Blvd., Pasadena	Corona
Valley Rock & Sand Corp.	a	San Jacinto	Moreno
Sacramento County:			
American River Sand & Gravel Co.	a	P.O. Box 156, Perkins	Perkins
Brighton Sand & Gravel Co.	a	P.O. Box 2604, Sacramento	Perkins
Cannon & Co.	c	Box 802, Sacramento	North Sacramento
Del Paso Rock Products Co.	a	3490 Fair Oaks Blvd., Sacramento	Del Paso
Fair Oaks Gravel Co.	a	1401 42d St., Sacramento 6	Fair Oaks

SAND, GRAVEL, AND STONE, MISCELLANEOUS—Continued

Operator	Product*	Address	Location of pit or quarry
Sacramento County—continued:			
McGillivray Construction Co.	a	P.O. Box 873, Sacramento	Sacramento
Pacific Coast Aggregates, Inc.	a, b	400 Alabama St., San Francisco	Fair Oaks, Prattrock and American River
Perkins Gravel Co.	a	Perkins	Perkins
M. R. Powell & Co.	a	Box 815, Sacramento	American River
J. R. Reeves	a, b	P.O. Box 1072, Sacramento	Sacramento
San Benito County:			
Granite Rock Co.	b	Box 151, Watsonville	Logan
San Bernardino County:			
A. T. & S. F. Ry. Co.	b	121 E. Sixth St., Los Angeles	Newberry
Columbia Construction Co.	b	Kaiser Bldg., 1924 Broadway, Oakland	Fontana
Consolidated Rock Products Co.	a, b	2730 S. Alameda St., Los Angeles	Claremont
Fontana Gravel Co.	a	Fontana	Fontana
Fourth St. Rock Crusher	a	P.O. Box 469, San Bernardino	San Bernardino
Hanawalt Bros., Sand & Gravel	a	Box 187, La Verne	Pomona
Geo. Herz & Co.	a	Base Line and Lytle, San Bernardino	San Bernardino
Holiday Rock Co.	a	Upland	Upland and Colton
Redlands Gravel Co.	a	305 S. Buena Vista St., Redlands	Redlands
San Bernardino Rock & Gravel Co.	a	1910 W. Seventh St., San Bernardino	San Bernardino
Triangle Rock & Gravel Co.	a, b	San Bernardino	San Bernardino
Union Pacific Railroad Co.	a	2025 Hunter St., Los Angeles	Baxter
San Diego County:			
Charles & Victor Arnell, Lakeside Sand Plant	a	Rt. 1, Box 10, Lakeside	Lakeside
Canyon Rock Co.	a, b	Box F, Hillcrest Sta., San Diego	San Diego
Caudell & Johnson	a	Box 246, Hillcrest Sta., San Diego	Mission Valley, Poway Valley
Crystal Silica Co.	a, h	717 E. 61st St., Los Angeles	Oceanside
Daley Corp.	a	Mission Valley & Ward Rd., San Diego	San Diego
Denton's Sand Plant, Edmond Denton	a	4166 Pepper Dr., San Diego	El Cajon
H. G. Fenton Material Co., Inc.	a	1245 National Ave., San Diego	San Diego
Hubbard Molding Sand Co.	c	2700 Barnson Pl., San Diego	San Diego
Martin Minerals	a	Vista	Vista
Mica Gem Mining & Milling Co.	a	Jacumba	Jacumba
John T. Momand	f	P.O. Box 381, Carlsbad	Carlsbad
Nelson & Sloan	a	Box 488, Chula Vista	Chula Vista

Carl Niemann	a	Del Mar	Del Mar
D. M. Sebastian	b	4330 Fairmont Ave., San Diego	San Diego
Vista Cement Products, A. J. McFall	a	P.O. Box 182, Vista	Vista
Woodward Sand Co., Arthur C. Woodward	a	2914 Bancroft St., San Diego	San Diego
San Joaquin County:			
Frank P. Brendel & Spencer S. Decker	a	1705 Oxford St., Berkeley	Stockton
Frank B. Marks & Sons	a	P.O. Box 668, Newman	Tracy
Pacific Coast Aggregates, Inc	a, b	400 Alabama St., San Francisco	Riverbank, Tracy, Kerlinger
Pereira Bros	a	Tracy	Tracy
Putnam Sand & Gravel Co	a	P.O. Box 486, Modesto	Riverbank
Santa Fe Sand & Gravel Co	a	Box 385, Escalon	Escalon
Sievers & Stigelmayer, Mokelumne Pit	a	Clements	Clements
Tracy Rock & Gravel Co	a	2101 Weber St., Stockton	Tracy
Clyde Wood	a	686 E. Lockwood St., Lodi	Clements
San Luis Obispo County:			
Guiton Molding Sand Co	a, c	Oceano	Oceano
Walter B. Roselip	a	Box 251, San Luis Obispo	Atascadero
San Mateo County:			
A. & B. Quarry	b	P.O. Box 1037, Redwood City	Woodside
Brisbane Rock Co	b	P.O. Box 638, Brisbane	Brisbane
Brumley-Donaldson Co	c	557 Howard St., San Francisco	South San Francisco
H. Morton	b	Box 192, Menlo Park	Redwood City
San Mateo Feed & Fuel Co	b	850 San Mateo Dr., San Mateo	Belmont
Rockaway Quarry, Inc	a, b	340 Pine St., San Francisco	Rockaway Beach
Ken Royce, Inc	b	185 Bayshore Blvd., San Francisco	Rockaway Beach
Shoreland Co	b	Pescadero	Pescadero
Peter Sorenson	b	927 Arguello, Redwood City	Belmont
Santa Barbara County:			
Miller Bros. Truck Co	a	10424 Washington Ave., South Gate	
Henry G. Petersen, dba Buell Flat Rock Co	a	Solvang	Solvang
Southern Pacific Milling Co	a	735 State St., Santa Barbara	Santa Maria
Santa Clara County:			
O. V. Freeman	b	495 California Ave., Palo Alto	
Harms Bros	b	5261 Stockton Blvd., Sacramento	
Los Gatos Aggregate Materials, Johnson & Rinehart	a	138 E. Main St., Los Gatos	Los Gatos
Los Gatos Sand and Gravel Co	a	Los Gatos	Los Gatos
George Neary	b	Rt. 1, Box 604, Los Altos	Los Altos

SAND, GRAVEL, AND STONE, MISCELLANEOUS—Continued

Operator	Product*	Address	Location of pit or quarry
Santa Clara County—Continued:			
Pacific Coast Aggregates, Inc.	a, b	400 Alabama St., San Francisco	Coyote and Campbell, San Jose
Permanente Cement Co.	b	Permanente	Permanente
A. J. Raisch Paving Co.	a	900 W. San Carlos St., San Jose	San Jose
Rhodes & Robinson, Stanford Quarry	b	Box 325, Palo Alto	Palo Alto
Western Gravel Corp.	a	P.O. Box 855, Campbell	Campbell
Santa Cruz County:			
Henry J. Kaiser Co.	a	1924 Broadway, Oakland	Olympia
Pacific Coast Aggregates, Inc.	a, b	400 Alabama St., San Francisco	Olympia
Santa Cruz Portland Cement Co.	b	Crocker Bldg., San Francisco	Davenport
Shasta County:			
Fairy-Hammond & R. A. Farish	a	564 Market St., San Francisco	Millville
Frederickson Bros.	b	1259 65th St., Emeryville	Anderson
Harms Bros.	a	5261 Stockton Blvd., Sacramento	Redding
J. H. Hein Co.	a	Redding	Redding
Oaks Sand, Gravel & Cement Products Co.	a, b	1737 Yuba St., Redding	Redding
Siskiyou County:			
Tom Hull	a	Eureka	Forks of Salmon
John S. Jensen & M. N. Thompson	a	Mount Shasta	Mount Shasta
Southern Pacific R. R. Co., Chief Engineer	c	Southern Pacific Bldg., San Francisco	Kegg
Solano County:			
Harms Bros.	a	5261 Stockton Blvd., Sacramento	Vacaville
Roy & Joe Manos	a	P.O. Box 455, Winters	Winters
J. M. Nelson, Cordelia Quarry	b	Cordelia	Cordelia
Parish Bros.	b	Benicia	Benicia
Sonoma County:			
Basalt Rock Co.	a, b	Eighth and River Sts., Napa	Healdsburg
Thomas A. Graham	b	Box 1, Occidental	Occidental
Hein Bros. Basalt Rock Co., Mark Hein, Pres.	b	Petaluma	Petaluma
Stony Point Quarry, W. A. Wilson	b	Petaluma, Star Route	Stony Point
Taylor Gravel Co., Harvey Taylor	a	Healdsburg	Healdsburg

Stanislaus County:			
Johnson Bros.	a	P.O. Box 123, Modesto	Modesto
Frank B. Marks & Sons	a	P.O. Box 668, Newman	Newman
Putnam Sand & Gravel Co.	a	P.O. Box 486, Modesto	Modesto
J. C. Scanlon, Scanlon Gravel Pit	a	Patterson	Newman
C. Skove & J. Wychopen	a	Rt. 1, Box 27, Turlock	Tuolumne River
Wallace Material Co.	a	Escalon	Escalon
Chas. D. Warner & Son, Inc.	a	Modesto	Modesto
Tehama County:			
Wm. G. Taber	a	Red Bluff	Red Bluff
Trinity County:			
Northwestern Pacific R. R. Co.	b	San Rafael	Island Mountain
Tulare County:			
O. C. Jeffers	a	1032 River Rd., Porterville	Porterville
Middletons	a	Visalia	Porterville
Pacific Coast Aggregates, Inc.	a, b	400 Alabama St., San Francisco	Lindsay
Sequoia Rock Co.	a	P.O. Box 133, Lemoncove	Lemoncove
Tuolumne County:			
Beerman & Jones	a	Sonora	Jamestown
Ventura County:			
Montalvo Rock Co.	a	Box 188, Montalvo	Montalvo
Santa Paula Rock Co.	a	Santa Paula	Santa Paula
Saticoy Rock Co.	a, b	Box 970, Ventura	Saticoy-Ventura
Ventura Molding Sand Co., O. D. Messmore	c	P.O. Box 1808, Ventura	Ventura
Yolo County:			
Leroy Kerr	a	Yolo	Yolo
Schwarzgruber & Sons	a, b	Woodland	Woodland
J. Dudley Stephens	a	Woodland	Esparto
Yuba County:			
Hallwood Sand & Gravel Co.	a	711 Wilkie Way, Yuba City	Marysville
Rice Bros.	a	P.O. Box 1446, Modesto	Marysville
Yuba River Sand Co.	a	Marysville	Marysville

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* a. Sand and gravel.
b. Crushed rock (macadam, ballast, rubble, riprap, etc.).
c. Molding sand.
d. Granules for roofing, terrazzo.
e. Slag and volcanic cinder.
f. Tube-mill pebbles.
g. Decomposed granite.
h. Filter sand.

SANDSTONE

Operator	Product*	Address	Location of quarry
Los Angeles County:			
Blue Goose Quarry, Robert Cox	b	1975 Lundy Ave., Pasadena	Pasadena
Monterey County:			
Carmel Stone Quarry, A. L. Possadori	c	Box 185, Carmel	Carmel
Napa County:			
H. F. Galbreath	b	957 Regal Rd., Berkeley	
Sonoma County:			
Roy J. Johns	b	P.O. Box 93, Boyes Hot Springs	Glen Ellen

* a. Dimension sandstone for building. b. Sandstone flagstone for building. c. Carmelstone for building.

SERPENTINE

Operator	Address	Location of quarry
Santa Clara County:		
The Permanente Metals Corp. (name changed to Kaiser Aluminum & Chemical Corp. on November 28, 1949.)	Permanente	Almaden

SILICA

Operator	Product*	Address	Location of mine
Kern County:			
N. W. Sweetser	a	Box 445, Rosamond	Rosamond
Monterey County:			
Del Monte Properties	b	Del Monte	Pacific Grove
Owens-Illinois Glass Co.	b	P.O. Box 359, Pacific Grove	Pacific Grove
Riverside County:			
Owens-Illinois Glass Co.	b	P.O. Box 298, Corona	Corona
San Bernardino County:			
Mineral Materials Co., C. W. Dunton, Mgr.	c	1145 Westminster Ave., Alhambra	Oro Grande

* a. Quartz. b. Glass sand. c. Quartzite.

SILVER

Principal silver producers in California in 1948. (Not less than 1,000 ounces.)

Mine	Type of mine*	Operator	Address	Postoffice of mine
Amador County:				
Belden	a	Belden Amador Mines, Inc.	Box 28, Fort Wayne, Ind.	Pine Grove
Inyo County:				
Cerro Gordo	k	Enterprise Mining Corp.	Beverly Hills	Keeler
Custer	b	L. D. Foreman & Co.	850 S. Fourth West St., Salt Lake City, Utah	Keeler
Darwin Group	m	Anaconda Copper Mining Co.	25 Broadway, New York, N. Y.	Darwin
Defense	k	Foreman & Skinner	850 S. Fourth West St., Salt Lake City, Utah	Panamint Springs

SILVER—Continued

Mine	Type of mine*	Operator	Address	Postoffice of mine
Inyo County—Continued:				
Empress Group	m	Joe McCulley	Box 53, Darwin	Darwin
Lane-Eagle	k	L. D. Foreman & Co.	850 S. Fourth West St., Salt Lake City, Utah	Keeler
Minnietta	k	Finley & Vignich	Panamint Springs Resort, Lone Pine	Panamint Springs
Pine Creek	p	United States Vanadium Corp.	30 E. 42d St., New York, N. Y.	Bishop
Queen of Sheba—Carbonate	k	New Sutherland Divide Mining Co.	958 Mills Bldg., San Francisco	Death Valley
Reward (Brown Monster)	k	T. L. Bright, et al.	Lone Pine	Independence
St. Charles	k	Porter Ryan Mining Corp.	Box 395, Lone Pine	Lone Pine
Santa Rosa	k	Santa Rosa Mining Co., et al.	Box 116, Keeler	Keeler
Shoshone Group	k	Anaconda Copper Mining Co.	25 Broadway, New York, N. Y.	Tecopa
Surprise	k	Foss & Osborne	441 Oxford Ave., Hawthorne	Panamint Springs
Ubehebe	m	Ubehebe Mines, Inc.	Box 111, Beatty, Nevada	Panamint Springs
Kern County:				
Standard	a	Earl Blickenstaff, et al.	Rosamond	Rosamond
Tropico, et al.	a	Burton Bros.	Rosamond	Rosamond
Whitmore	b	Jim Ritchie	Mojave	Mojave
Mariposa County:				
Mount Gaines	a	Mount Gaines Mining Co.	Hornitos	Hornitos
Merced County:				
Snelling Dredge	f	Snelling Gold Dredging Co.	Snelling	Snelling
Nevada County:				
Empire Star, et al.	a	Empire Star Mines Co., Inc.	Box 1027, Grass Valley	Grass Valley
New Brunswick-Idaho Maryland	a	Idaho-Maryland Mines Corp.	368 Russ Bldg., San Francisco	Grass Valley
Sacramento County:				
Natomas Dredges	f	Natomas Co.	Box 1197, Sacramento	Natoma
San Bernardino County:				
Annex (Silver Hill)	b	California Silver Corp.	5177 Overland Ave., Culver City	Renoville (via Baker)
Bagdad-Chase	a	Donald F. Love	Ludlow	Ludlow
Carbonate King Zinc	l	Crystal Cave Mining Co., (J. Q. Little)	Nipton	Nipton
Kelly	c	Frank Royer	Randsburg	Randburg
Mohawk	k	Mohawk Mines, Inc.	Nipton	Nipton
Wilshire	k	Altana Corp., et al.	Nipton	Nipton

Shasta County:				
Afterthought	s	Coronado Copper and Zinc Co.	1206 Pacific Mutual Bldg., Los Angeles	Bella Vista
Iron Mountain-Hornet-Richmond	n, o, & q	The Mountain Copper Co., Ltd.	216 Pine St., San Francisco	Matheson
Sierra County:				
Original 16 to 1	a	Original Sixteen to One Mine, Inc.	1611 Russ Bldg., San Francisco	Alleghany
Siskiyou County:				
Siskiyou Unit	f	Yuba Consolidated Gold Fields	351 California St., San Francisco	Callahan
Yuba County:				
Yuba Unit	f	Yuba Consolidated Gold Fields	351 California St., San Francisco	Hammonton

* a. Lode gold mine
b. Silver mine
c. Gold-silver mine
f. Dredge (bucket line)
k. Lead mine
l. Zinc mine
m. Zinc-lead mine
n. Pyrite mine
o. Terminal cleanup
p. Tungsten mine.
q. Leaching operation
s. Zinc-lead-copper mine

SLATE

Operator	Product*	Address	Location of quarry
El Dorado County:			
Pacific Minerals Co., Ltd.	b, c	337 10th St., Richmond	Chili Bar
Inyo County:			
Blue Star Mines, Ltd.	d	810 S. Spring St., Los Angeles	Bigpine
James F. Nikalous	b	109 S. Main St., Bigpine	Bigpine
Mariposa County:			
Hanner Mining Co.	a, c	Box 130, Le Grand	Le Grand

* a. Facing. b. Granules. c. Crude. d. Filler.

SODA

Operator	Product*	Address	Location of plant
Inyo County:			
Natural Soda Products Co.	a, d	506 Central Tower Bldg., San Francisco 3	Keeler
Permanente Metals Corp.	a	Kaiser Bldg., Oakland 12	Lone Pine
Pittsburgh Plate Glass Co., Columbia Chemical Division	a, d	Bartlett	Bartlett
San Bernardino County:			
American Potash & Chemical Co.	a, c	3030 W. Sixth St., Los Angeles 54	Trona
Dale Chemical Industries, Inc.	c	P.O. Box 319, Twenty-nine Palms	Twenty-nine Palms
West End Chemical Co.	a	608 Latham Sq. Bldg., Oakland 12	Westend

* a. Soda ash. c. Salt cake. d. Trona.

SULFUR

Operator	Address	Location of mine
Alpine County:		
Siskon Mining Corp., Hugh Wright, Gen. Mgr.	812 Subway Terminal Bldg., Los Angeles 13	Markleeville
Inyo County:		
Crater Group, R. E. Kitching	P.O. Box 783, Bigpine	Bigpine

TALC, PYROPHYLLITE, AND SOAPSTONE

Operator	Product*	Address	Location of mine
El Dorado County:			
Pacific Minerals Co., Ltd.	a	337 10th St., Richmond	Shingle Springs
Inyo County:			
Stuart M. Anderson	b	Box 11, Darwin	Darwin
William Bonham	b	Lone Pine	Keeler
Louise Grantham	b	809 E. Sixth St., Ontario	Shoshone
F. M. Henderson	b	Box 24, Moapa, Nev.	Bigpine
T. O. Imus	c	Bigpine	Bigpine
George W. Koest	b	Darwin	Darwin
Little & Hildebrand	b	P.O. Box 15, Bigpine	Bigpine
James F. Nikolaus	b	109 S. Main St., Bigpine	Bigpine
Sierra Talc & Clay Co.	b	5509 Randolph St., Los Angeles 22	Keeler, Tecopa, and Shoshone
H. N. Stewart & Homer Taylor	b	Bigpine	Lone Pine
Los Angeles County:			
Dr. Leon Katz	a	3239 Weldon Ave., Los Angeles 41	Acton
Mono County:			
Charles Bowen	c	Laws	Laws
Huntley Industrial Minerals, Inc.	c	P.O. Box 305, Bishop	Laws
San Bernardino County:			
Desert Talc & Clay Co.	b	Pomona	Yucca Grove
Sierra Talc and Clay Co.	b	5509 Randolph St., Los Angeles 22	Baker and Shoshone
Southern California Minerals Co., W. S. Skeoch	b	320 S. Mission Rd., Los Angeles	Yucca Grove and Shoshone
Western Talc Co.	b	1901 E. Slauson Ave., Los Angeles	Tecopa
San Diego County:			
Pioneer Pyrophyllite Products	c	Box 686, Chula Vista	Cardiff

* a. Soapstone. b. Talc. c. Pyrophyllite.

TITANIUM

Operator	Address	Location of mine
Los Angeles County:		
Challoner Thompson	Sand Canyon Rt. 1, Saugus	Saugus
Ferro-Titan Minerals Co., N. C. Amen & F. M. Moody	212 Bank of American Bldg., Glendale	Saugus

TUNGSTEN

Mine	Operator	Address	Location of mine
Alpine County:			
Alpine	Alpine Mining Co.	P.O. Box 114, Gardnerville, Nev.	Markleeville
Fresno County:			
Garnet Dike	Sheridan & Bennett	Fresno	Kings River
Inyo County:			
Brownstone	El Diablo Mining Co.	Box 567, Bishop	Bishop
Hanging Valley	Hanging Valley Tungsten Co.	1545 W. 87th St., Los Angeles 44	Bishop
L. & L.	Lester Brown	Box 674, Bishop	Bishop
Pine Creek	U. S. Vanadium Corp.	30 E. 42d St., New York, N. Y.	Bishop
Round Valley	O. A. Kittle Mining & Exploration Co.	Box 478, Bishop	Bishop
Tungstar	Tungstar Corp.	Rt. 2, Bishop	Bishop
	C. H. Brooks	1505 W. Fifth St., Santa Ana	Bishop
Kern County:			
Bluebird	L. J. Sain	Box 342, Randsburg	Randburg
Rand	Kubon & Jurva	4104 W. 104th St., Inglewood	Glenville
Tungsten Chief	W. C. Thompson	20728 Ventura Blvd., Woodland Hills	Caliente
Madera County:			
Strawberry	Fresno Mining Co.	415 Brix Bldg., Fresno	Bass Lake

Mono County:			
Black Rock	Tungstar Corp.	Rt. 2, Bishop	Benton
San Bernardino County:			
Spud Patch Placers and Atolia	Surcease Mining Co.	P.O. Box 786, Sacramento	Atolia
Tulare County:			
Big Jim	Tulare County Tungsten Mines	Box 361, Lindsay	Lindsay
Harrel Hill	Consolidated Tungsten	Box 366, Dinuba	Orosi
Herbert	Herbert Mines	Rt. 5, Box 150A, Porterville	Porterville
Sherman Peak	Embree & Eliason Mining Co.	P.O. Box 583, Kernville	Kernville

ZINC

Principal zinc producers in California in 1948. (Not less than 10,000 pounds.)

Mine	Operator	Address	Postoffice of mine
Inyo County:			
Darwin Group	Anaconda Copper Mining Co.	25 Broadway, New York, N. Y.	Darwin
Empress Group	Joe McCulley	Box 53, Darwin	Darwin
Gold Bottom-Ophir	Damon & Damon	1612 Orange, Redding	Trona
Shoshone Group	Anaconda Copper Mining Co.	25 Broadway, New York, N. Y.	Tecopa
Ubehebe	Ubehebe Mines, Inc.	Box 111, Beatty, Nevada	Panamint Springs
San Bernardino County:			
Carbonate King Zinc	Crystal Cave Mining Co., (J. Q. Little)	Nipton	Nipton
Shasta County:			
Afterthought	Coronado Copper & Zinc Co.	1206 Pacific Mutual Bldg., Los Angeles	Bella Vista

LIST OF SMELTERS AND MINERAL DEALERS REPORTING PURCHASE OF CALIFORNIA METALS PRODUCED IN 1948.

Name	Address	Location of plant	Metals reported purchased
American Smelting & Ref. Co.	120 Broadway, New York, N. Y.	Garfield, Utah	Copper, lead, gold, silver
American Smelting & Ref. Co.	120 Broadway, New York, N. Y.	Hayden, Arizona	Copper, gold, silver
American Smelting & Ref. Co.	120 Broadway, New York, N. Y.	Murray, Utah	Lead, copper, gold, silver
American Smelting & Ref. Co.	405 Montgomery St., San Francisco	Selby, California	Copper, lead, gold, silver
American Smelting & Ref. Co.	120 Broadway, New York, N. Y.	Tacoma, Washington	Copper, lead, gold, silver
Anaconda Copper Mining Co.	25 Broadway, New York 4, N. Y.	Great Falls, Mont.	Copper, lead, zinc, gold, silver
Bethlehem Pacific Coast Steel Corporation	20th and Illinois Sts., San Francisco	San Francisco	Iron ore
Bradley & Ekstrom	320 Market St., San Francisco	San Francisco	Manganese, chromite, iron ore
Braun Corporation	2260 E. 15th St., Los Angeles	Los Angeles	Quicksilver
Coast Chemical Division F. W. Berk & Co., Inc.	Sharon Bldg., San Francisco	San Francisco	Quicksilver
International Smelting & Ref. Co.	Kearns Bldg., Salt Lake City, Utah	Tooele, Utah	Copper, lead, zinc, gold, silver
Kaiser Co., Inc.	P.O. Box 217, Fontana	Fontana	Iron ore, manganese ore, chromite
Mefford Chemical Co.	1026 Santa Fe, Los Angeles	Los Angeles	Quicksilver
Pacific Vegetable Oil Co., Bernard T. Rocca	62 Townsend St., San Francisco	San Francisco	Quicksilver
Quicksilver Producers Ass'n., Irving Ballard, Sec'y.	407 Sansome St., San Francisco	San Francisco	Quicksilver
Twining Laboratories	2527 Fresno St., Fresno	Fresno	Tungsten ore
U. S. Mint	Duboce & Market Sts., San Francisco	San Francisco	Gold, silver
U. S. Smelting, Refining & Mining Co.	Newhouse Bldg., Salt Lake City, Utah	Midvale, Utah	Copper, lead, zinc, gold, silver
Western Gold & Platinum Works	589 Bryant St., San Francisco	San Francisco	Platinum, gold, silver*
Wildberg Bros. Smelting & Ref. Co.	742 Market St., San Francisco	San Francisco	Platinum, gold, silver*

* Gold and silver in special high-grade ores only.

LIST OF MINERAL DEALERS, CUSTOM MILLS, AND COMMERCIAL GRINDING PLANTS IN CALIFORNIA

FIRM	NOTES
American Minerals Co., 840 Mission Rd., Los Angeles, Calif.	Commercial grinding of minerals.
Atkins, Kroll & Co., 320 California St. San Francisco 4, Calif.	Dealer in tungsten ores, mercury, gypsum and limerock.
Baroid Sales Division, National Lead Co., 830 Ducommun St., Los Angeles, Calif.	Talc and other soft non-metallic minerals ground by contract or purchased.
Bishop Concentrate & Cleaning Co., Bishop, Calif.	Custom mill; purchase tungsten ores and base metal ores.
Blood, Harry E., Co., 5028 Alhambra Ave., Los Angeles, Calif.	Dealer in industrial sand and silica products.
Blue Star Mines, Ltd., 667 S. Anderson, Los Angeles, Calif. (Mill at Zurich)	Dealer in talc, clay, and limestone.
Bond Bros. & Co., 461 Market St., San Francisco 5, Calif.	Dealer in export minerals.
Bradley & Ekstrom, 320 Market St., San Francisco 11, Calif.	Dealer in all commercial minerals.
Brumley-Donaldson Co., 557 Howard St., San Francisco 5, Calif. and 3050 E. Slauson Ave., Huntington Park, Calif.	Dealer in sand, clay, limestone, dolomite, and other minerals.
Burton Bros., Rosamond, Calif.	Custom cyanide mill. Gold and silver ores purchased.
Butte Lode Mining Co., Randsburg, Calif.	Custom amalgamation mill, gold-silver ore.
Commercial Minerals Co., 310 Irwin St., San Francisco 7, Calif.	Commercial grinding by contract or minerals purchased.
Dailey Chemical Laboratories, Box 228, Oroville, Calif.	Custom mill for black sands.
Empire Star Mines Co., Ltd., Grass Valley, Calif.	Amalgamation and cyanide mill; gold ore purchased.
Hidecker Co., 800 S. Mission Rd., Los Angeles, Calif.	Clay grinding plant; non-metallic minerals ground by contract or purchased.
Hill Bros. Chemical Co., 2159 Bay St., Los Angeles, Calif.	Grinding asbestos, and custom milling of small lots of soft non-metallic minerals.
Huntley Industrial Minerals, P. O. Box 305, Bishop, Calif.	Dealer in talc, pyrophyllite, asbestos, and garnet sands.
Industrial Minerals & Chemical Co., 836 Gilman St., Berkeley, Calif.	Non-metallic minerals ground by contract or purchased.
Kennedy Minerals Co., 2550 E. Olympic Blvd., Los Angeles, Calif.	Non-metallic minerals ground by contract or purchased.

Los Angeles Chemical Co., 1960 S. Santa Fe Ave., Los Angeles, Calif.	Dealer in non-metallic minerals.
Ontario Rock Milling Co., 7750 E. Madison, Paramount, Calif.	Non-metallic minerals ground by contract or purchased. Roofing granules prepared.
Sierra Talc & Clay Co., 5509 Randolph St., Los Angeles 22, Calif.	Dealer in talc and clays.
Southern California Minerals Co., 320 S. Mission Rd., Los Angeles, Calif.	Non-metallic mineral grinding plant; minerals ground by contract or purchased.
Twining Laboratories, 2527 Fresno St., Fresno, Calif.	Purchase and concentrate tungsten ores on a custom basis; also commercial grinding.

LIST OF COMMERCIAL ASSAY AND TESTING LABORATORIES

SAN FRANCISCO AREA

Ball, C. M.,
911 University Ave.,
Berkeley 21, Calif.
Curtis & Thomkins,
236 Front St.,
San Francisco 11, Calif.
Hall Laboratories, Inc.,
200 Davis St.,
San Francisco 11, Calif.
Hanks, Abbott A., Inc.,
624 Sacramento St.,
San Francisco 11, Calif.
Hersey Inspection Bureau (engineers, chemists, and testers of building materials),
3405 Piedmont Ave.,
Oakland, Calif.
Hunt, Robert W., Co.,
251 Kearny St.,
San Francisco 8, Calif.
Metallurgical Laboratories,
604 Mission St.,
San Francisco 5, Calif.

Multiphase, Inc.,
351 Eighth St.,
San Francisco 3, Calif.

Pacific Chemical Laboratories,
617 Montgomery St.,
San Francisco 11, Calif.

Pittsburgh Testing Laboratories,
651 Howard St.,
San Francisco 5, Calif.

Straub Manufacturing Co.,
507 Chestnut St.,
Oakland, Calif.

Western Analytical Bureau,
690 Market St.,
San Francisco 2, Calif.

Western Gold and Platinum Works,
589 Bryant St.,
San Francisco 7, Calif.

Wildberg Bros.,
742 Market St.,
San Francisco 3, Calif.

LOS ANGELES AREA

California Testing Laboratories, Inc.,
1429 Santa Fe Ave.,
Los Angeles 21, Calif.
Eisenhauer, Ed, Jr.,
322 S. San Pedro St.,
Los Angeles, Calif.
Fess, Edward E.,
5905 Pacific Blvd.,
Huntington Park, Calif.
Groch, Geo. W., Laboratories,
2580 E. 8th St.,
Los Angeles, Calif.
Herman, John
920 Santee St.,
Los Angeles 15, Calif.
Herr, A. V.,
5176 Hollywood Blvd.,
Los Angeles, Calif.
Hollywood Testing Laboratories,
1257 N. La Brea Ave.,
Hollywood 38, Calif.
Hunt, Robert W., Co.,
6353 Miles Ave.,
Huntington Park, Calif.
Kennard & Drake,
4686 S. Santa Fe Ave.,
Los Angeles 11, Calif.
Lewis & Walker,
111 W. 11th St.,
Los Angeles, Calif.

LOS ANGELES AREA—Continued

Los Angeles Testing Laboratory,
1300 S. Los Angeles St.,
Los Angeles 15, Calif.
Meco Assayers,
417 S. Hill St.,
Los Angeles 13, Calif.
Metal Control Laboratories,
1220 Maple Ave.,
Los Angeles 15, Calif.
Minerals Engineering,
417 S. Hill St.,
Los Angeles 13, Calif.
The National Supply Co.,
1524 Border Ave.,
Torrance, Calif.
Osborne, Raymond G., Laboratories,
110 W. Ninth St.,
Los Angeles 15, Calif.

Pacific Platinum Works,
253 S. Broadway,
Los Angeles, Calif.

Sill, Harley A.,
1011 S. Figueroa St.,
Los Angeles 15, Calif.

Smith-Emery Co.,
920 Santee St.,
Los Angeles 15, Calif.

von Huene, Rudolph (thin sections),
865 N. Mentor Ave.,
Pasadena, Calif.

Ward, S. Paul, Inc. (ceramic testing)
605 Mission St.,
South Pasadena, Calif.

OTHER AREAS

Brooks, Alan M.,
275 H St., or Box 893,
Chula Vista, Calif.
Clarkson Chemical Laboratories,
1548 6th Ave.,
San Diego, Calif.
Coast Laboratory,
1859 S. Van Ness Ave.,
Fresno, Calif.
Daily Chemical Laboratory,
Box 228,
Oroville, Calif.
Harris, Robert J.,
1235 Sierra Way,
San Bernardino, Calif.
Hornkohl Laboratories,
716 Truxton Ave., or Box 1673,
Bakersfield, Calif.
King, James
4902 Palm St.,
Fresno, Calif.
Morse Laboratories,
316 16th St.,
Sacramento, Calif.
Ott, E. J. N.,
130 Main St.,
Nevada City, Calif.
Raggio, A. J.
Jackson, Calif.
Rombaugh, M. D.,
3069 Del Paso Blvd.,
North Sacramento, Calif.
San Joaquin Research Laboratory,
8 W. Weber St., Box 1987,
Stockton, Calif.
Scheave, Harold,
232 Commercial St.,
Nevada City, Calif.
Twining Laboratories,
2527 Fresno St., Box 1472,
Fresno, Calif.

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